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We exploit variation in the composition of local fish catches around the time of birth using large-scale administrative and census data on adult cognitive test scores, schooling attainment, and occupation among coastal populations in Colombia to estimate the distinct causal effects of methylmercury (*MeHg*) and DHA, elements contained in fish, on cognitive development. Using an IV strategy based on an equilibrium model of fish supply that exploits time-series variation in oceanic SST anomalies on both coasts of Colombia from 1950 to 2014 as instruments, we find that net of cohort and municipality fixed effects increases in high-*MeHg* fish catches around a cohort's birth, net of rainfall variation in the same interval, negatively affect the cohort's verbal and math test scores upon exiting high school and their likelihood of continuing their schooling, while increasing the likelihood the cohort is disproportionally represented in manual-labor occupations. In contrast, for given levels of early-life high-*MeHg* fish supply, increases in early-life catch sizes of low-*MeHg* fish raise verbal and math test scores and educational attainment and lower the likelihood of being a manual laborer.

JEL Codes: O15, J13, Q22, Q53

For pregnant women and very young children in particular, fish can be an essential component of a nutritious diet, as it contributes to neurodevelopment during the most crucial stages of an unborn or young child's growth. FAO, 2018, p.69.

Over three billion people in the world obtain 20% of their total animal protein from fish, with per-capita fish-consumption growing at over 1.8% per year since 1961. While protein is a smaller percentage of the diets of households in low-income countries, fish in such countries form a higher fraction of total protein intake compared with populations in high-income countries. The FAO regards the increased consumption of fish and the relatively greater fish consumption in developing countries as beneficial, specifically by enhancing the neurological development of children. However, the United Nations 2018 Global Mercury Assessment report indicates that the consumption of fish by pregnant women and recent mothers is a "concern" due to many fish species containing high levels of organic mercury (methylmercury) that inhibit brain development (UN, 2018, p.52).

There is medical evidence supporting both points of view on the cognitive benefits and shortcomings of early-life fish consumption, based on the fact that fish are unique among foods in containing unusually high levels of elements that both stimulate and inhibit brain development in fetuses and young children. The beneficial components found in fish and seafood are two of the three main omega-3 fatty acids - eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The body cannot produce sufficient amounts of these acids so that consuming fish is important to maintain optimal levels of these fatty acids in the body. DHA is the principal omega-3 fatty acid in brain grey matter, and it has been shown that DHA is beneficial for brain development by promoting the structural development of neurons (Tofail *et al*., 2006). On the other hand, methylmercury, which is almost exclusively found in fish, is known to cross the blood brain barrier in young children, targeting the central nervous system and inhibiting the division of neuronal cells and disrupting the cytoarchitecture of the brain (Clarkson, *et al*., 2003).

Thus, while fish is indeed brain food, it may also be brain poison. The medical evidence on the beneficial aspects of fish consumption and specifically of DHA on cognition is large, and mostly reports positive or insignificant effects on cognitive outcomes. In a major review article (Innis, 2008) concludes that low levels of DHA reduce cognitive function in infants and young children. Some of the studies in the medical literature employ randomized control trials. For example, Drover *et al.* (2011) follow an RCT in which there is randomized variation in the DHA content of infant formula during the first year of life. Cognitive tests assessed at 18 months of age indicate that children with DHA in their formulas had better language skills than did the controls with no DHA supplementation. MRI studies embedded in RCTs, such as McNamara *et al.* (2010), find that DHA supplementation increases prefrontal cortex activation, the brain region associated with planning complex cognitive behavior, during sustained attention tests among infants.

None of the evidence on the direct adverse effects of methylmercury (*MeHg*) consumption on human cognition, however, are based on RCT's. This is not surprising. While there are no prohibitions on randomized diet interventions with hypothesized beneficial supplements, such as iron (Bobonis *et al*., 2006), or iodine (Field *et al*., 2009) or proteins (Puentes *et al*., 2016) or non-nutrient interventions that are unlikely in the worst case to cause harm, such as early-age behavioral interventions (e.g., Gertler *et al*., 2014), it is not possible to undertake an intervention that feeds poison to human subjects.[1] Thus, all of the existing evidence

[1] For the same reason, it is difficult to identify the effects of the ingestion of inorganic arsenic, found in tubewell water in Bangladesh, for example, on human outcomes using an RCT. Pitt *el al*. (forthcoming) use molecular genetics models and variation in family linkages to identify arsenic ingestion on cognitive ability and health outcomes. Here we use climate models and findings from marine biology and medical science to aid in the identification of the effects of methylmercury consumption.

on the adverse cognitive effects of methylmercury is observational, based for example on the methylmercury found in the hair samples of mothers and assessments of their young children.[2] Because the variation in methylmercury consumption is based on dietary choices, the findings, for example, that populations near coasts, with elevated fish consumption and high measured mercury found in hair samples, are characterized by children with lower IQ, cannot rule out that low incomes are the fundamental cause.

There are thus three main deficiencies in the existing medical evidence on the effects of fish consumption on the brain development of children. First, no individual study separates the distinct effects of DHA and methylmercury, as is noted in the medical literature (Kvestad *et al*. (2018). Second, there is little evidence linking early-age fish consumption to adult outcomes. Third, there is no causal evidence on the adverse effects of the methylmercury content of fish on cognitive development in human populations at any age.

In this paper, we exploit variation in the composition of local fish catches around the time of birth using large-scale administrative and census data on adult cognitive test scores, schooling attainment, and occupation among coastal populations in Colombia to estimate the distinct causal effects of both methylmercury and DHA on cognitive development. Our identification strategy uses the insights and models of climate science and marine biology, embedded in an equilibrium economic model in which exogenous changes in relative fish supplies affect relative prices.

[2] An exception is Kvestad *et al*. (2018) RCT, which attempted to assess the effects of methylmercury (*MeHg*) consumption among children on cognitive tests. In their study, children 4 to 6 years old are randomized lunch meals with fish or meat for 16 weeks. However, the fish lunch meal consisted of Mackerels and Herrings, which are fish species with low mercury content, as we document below. Thus, while Total Hair *MeHg* (*THHg*) increased in the fish group, children in that group outperformed children in the meat group in cognitive tests. One cannot rule out that children supplemented with fish experienced the benefits from the Docosahexaenoic content of these low-mercury fish, which is what we find. There are two other limitations to the study design: First, parents might have responded to the meal interventions by adjusting nutrition within the household. Second, the intervention period does not correspond to the period when the brain is forming.

Bacteria in the sea transform inorganic mercury that is in water to methylmercury, with the amounts of the latter in fish increasing along the fish food chain.[3] Fish species thus differ in their *MeHg* content because of this biomagnification, with *MeHg* empirically uncorrelated with DHA across species. Because fish also differ in the range of water temperatures in which they thrive, changes in sea surface temperatures (SSTs) due to climate (trade winds) variation alter the relative supplies of low- and high-*MeHg* fish from year to year but there is no literature that suggests that SST variation, except via rainfall fluctuations, have direct effects on human brain development.

Using an IV strategy that exploits time-series variation in oceanic SST anomalies on both coasts of Colombia as instruments, net of municipality fixed effects, we find that increases in high *MeHg* fish catches around a cohort's birth, net of rainfall variation in the same interval, negatively affect the cohort's verbal and math test scores upon exiting high school and their likelihood of continuing their schooling, while positively increasing the likelihood the cohort is disproportionally represented in manual-labor occupations. In contrast, for given levels of early-life high-MeHg fish supply, increases in early-life catch sizes of low-*MeHg* fish raise verbal and math test scores and educational attainment and lower the likelihood of being a manual laborer. We find no evidence, however, that variation in the composition of fish supply at later ages, given the variation in early childhood, has any effect on these adult outcomes, consistent with the fact that children are more vulnerable to the ingestion of poisons because of the incomplete development of the adult blood-brain barrier at young ages (Currie and Vogl, 2013). We also

[3] There are two sources of inorganic mercury that is found in the sea – pollution of the air, primarily by coal-burning, from industry, dating back to the industrial revolution and direct seepage mainly from the historical mining of gold in the Americas. The vast majority of mercury is from the sixteenth century, as mercury is an indestructible inorganic element. Reduction in industrial emissions today thus will have little effect on the mercury content of the world's waters for the foreseeable future.

find that while the net effect of total fish catches around birth on these skill measures is insignificant, increases in the total catch size, but not the composition of the catch, increase height, consistent with fish being a high-protein food and with *MeHg* affecting only brain development and not physical growth.

The issue of the cognitive effects of fish consumption on cognitive outcomes is particularly salient not only for low-income countries but for poor populations within those countries. In Colombia, fish is significantly more likely to be fed to young children among the poorest households, even among households not residing near coasts. The 2010 Demographic and Health Survey for Colombia provides information on foods fed to children aged 9-24 months in the day before the survey. Figure 1 displays the fraction of children in this age group by the five household wealth categories provided in the survey for the all mothers in Colombia aged 13-49 and for those residing in coastal communities. The data, weighted to be representative of the population in the survey year, indicate that for Colombia as a whole, children in the bottom 20% of the wealth distribution are over three times more likely to be fed fish than children whose mothers are in the middle wealth category. Among those children residing on the Colombia coasts, the ratio across wealth categories is similarly high, but the children on the coasts in the lowest wealth category are 1.7 times more likely to be fed fish than the average Colombian child in the same household wealth category.

Figure 2 shows that children in the poorest households are also less likely to consume animal protein compared with children residing in all other households, although the wealth gradient is far less steep. Together, Figures 1 and 2 indicate that fish constitutes a much larger fraction of overall protein consumption among children in the poorest households in Colombia.[4] Figure 3 based on data from the second round of the *Encuesta Longitudinal Colombiana de la Universidad de los Andes* (ELCA, 2013) hints at the cognitive effects of overall fish consumption. These data provide results for the Ravens test for children aged three to nine years and are representative of the population in the four (of six) bottom income categories in the Colombia population. The households are geo-coded, enabling construction of a measure of coastal distance for each household. The figure shows, by per-capita income quintiles, age-standardized test scores for children in communities less than and more than 100 kilometers from a coast. As can be seen, test scores are lower in the bottom two income categories among coastal as opposed to non-coastal children. This gap is statistically significant. However, the pattern is reversed in the next two quintiles, despite the fact that fish consumption among young children is still much more likely in coastal households in these categories. These patterns of course are only informative about the average effects of fish consumption. They key point of the literature on the properties of fish is that the composition of fish consumed matters, given the potential opposite effects of DHA and *MeHg* and the heterogeneity across fish species in both elements.

Our study of the causal effects of low-*MeHg* and high-*MeHg* fish availability around the birth of children – from conception through age three – on later-life outcomes is part of a large and still growing economics literature using natural experiments examining the life-cycle effects of early-age environmental and economic change. Studies of this type in low-income countries focus, however, on the overall effects of income deprivation. For example, Adhvaryu *et al*. (2019) exploit early-life variations in cocoa prices on adult mental health in Ghana, but as cocoa

[4] Overall (not shown), children aged 9 to 24 months in the lowest wealth category are 50% more likely to have not been fed any protein compared with children in the rest of the population.

is a major exported cash crop, the variation in price identifies income effects. Thus, there are multiple mechanisms by which the forcing variable and the outcomes are linked and it is not possible to identify the causal effect of any one mechanism. Maccini and Yang's (2009) study of the effects of early-life rainfall on adult outcomes in Indonesia does not identify the specific behaviors due to deprivation that affect the outcomes examined. Our study uses variations in early-life fish supply which, by affecting relative prices in equilibrium, affect diet composition, from which we can, as we show, separately identify the negative cognitive effects of high-*MeHg* and the positive cognitive effects of low-*MeHg* fish consumption.

Given that the source of *MeHg* in fish is a pollutant, mercury, our study also contributes to the literature on the direct effects of early-life exposure to pollutants (e.g., Almond *et al*., 2009). And, given that our principle determinant of the variation in fish supply composition is climate variation, our study also links to the literature on the effects of climate variation around birth on human outcomes (e.g., Deschenes *et al*., 2009), although our study identifies a specific mechanism linking climate variability in childhood to adult cognition.

In section II, we set out a simple price-theory consumption model to first illustrate the difficulty of identifying the effects of low-and high-mercury fish on cognition from any RCT that subsidizes low-mercury fish consumption, which would be the only feasible experiment. The main message is that it is not possible to identify the sign of the effect on any outcome measure from encouraging a switch to any specific food, as the effect will depend on which other foods are consumed less and on their effects. We then embed the model in a general-equilibrium context to show that by using information on aggregate fish catches of the two types of fish we can identify the sign of the effects of each fish type on cognition if fish markets are local.

Section III contains a description of the data on catch sizes by fish species on the Atlantic and Pacific coasts of Colombia covering the period 1950-2014, information on the DHA and *MeHg* content of the 43 locally-caught and consumed fish species, and displays the time-series of Atlantic and Pacific SSTs over the same period. Using the definition of SST anomalies (temperature changes) used by climate scientists to define El Niño and La Niña episodes in the Pacific, we show that by using eight variables that categorize these anomalies by incidences of negative and positive deviations along with the mean values of those deviations on each coast, we can explain over 30% of the variation in total fish catches and over a third of the variation in high-*MeHg* fish catches over the 65-year period due to the heterogeneity in temperature ranges in which fish species can survive. We also show that our SST variable set for the Pacific coast explains as much of the variation in Colombia sea-coast rainfall (90%) over the period 1963-2015 as does the set of variables used in the standard Ocean Niño Index (ONI) model of climate scientists.

In section IV we show using the Colombia DHS that with a large set of controls characterizing mothers and households, young children in coastal municipalities are twice as likely to be fed fish compared with non-coast children and that within coastal municipalities fish is significantly more likely to be fed to children the higher the proportion of the municipality's border that is oceanic coastline. We also show that the relationship between retail price of fish and distance to the coast has a negative gradient, while that for meat has a positive gradient. We then estimate, using the time-series of total fish catches and the (real) price series of fish, the effect of total fish supply on the real price of fish using an IV strategy in which the eight SST anomalies variables are used to predict fish catch size. The estimates indicate, as expected, that, net of rainfall variation, the coastal fish price is lower when fish are abundant, as is assumed in the model, with the IV estimate indicating that the OLS relationship is positively biased.

In the next section we describe our identification strategy for estimating the early-life causal effects of the supply of low- and high-*MeHg* fish by pregnant mothers and young children on children's skill outcomes (test scores, schooling, occupation classification) later in life. The IV-FE econometric model exploits the relationships between the SST variables and species-specific fish catches and the fact that within coastal areas the fraction of the coastline matters for fish consumption. The key exclusion restriction is that, conditional on rainfall and municipality and cohort fixed effects, the set of anomalies in ocean-specific SSTs affect skill outcomes only through their effects on the variation in the fish catches.

Section VI contains the estimates, based on government administrative records of the exams (SABER 11) taken by all exiting high school seniors in Colombia in the years 1980 through 2015, of the effects of early childhood fish catches on both math and verbal achievement test scores. The IV-FE estimates indicate that while total catch sizes in the first four years of life post conception have no significant effects on either test score, increases in early-life high-*MeHg* fish catches, net of the size of the low-*MeHg* fish catch around birth, significantly decrease both scores at age 17, while for given size of early-life high-*MeHg* fish supply, an increase in the size of the low-*MeHg* catch significantly increases both test scores. These findings, which are robust to the inclusion of early-life rainfall variation, are consistent with the medical literature and folklore that fish is indeed "brain" food, but represent as far as we know the first casual estimates indicating that some fish, because of their *MeHg* content, are poison for the brain.

In the next section, we show in a placebo test using a long time-series of administrative records on all applicants around age 18 seeking a government ID card that, consistent with the medical literature indicating that early-life protein affects adult height, an increase in the total fish catch around birth increases height. However, as expected, the composition of the fish catch with respect to *MeHg* does not affect physical growth. We also show using the test score records that early-in-life fish catch sizes matter more for cognitive development than do fish catch variations occurring later in the life cycle, as suggested by the medical literature on child development.

In section VIII we use data from the Colombia Census of 1993 to estimate the effects of the composition of around-birth coastal fish catches on adult schooling attainment and occupation for persons born in coastal municipalities. Consistent with our findings on test scores, we find that early-life high-*MeHg* fish catches lower the probability of attaining any post-secondary schooling and increase the probability that one has a manual-labor job, while the opposite is true, *ceteris paribus*, for the size of the low-*MeHg* fish catch. Finally, in the conclusion we summarize our findings in the context of the externalities of industrial pollution and suggest how climate change may alter diets and the future cognitive development of children in poor families.

II. Model

We set out a simple price-theory consumption model to first illustrate the difficulty of identifying the effects of low-and high-mercury fish on cognition from an experiment randomly subsidizing low-mercury fish consumption. This generalizes to the fact that it is not possible to identify the sign of the effect on any health measure from encouraging a switch to any particular food, as the effect will depend on which other foods are consumed less and on their effects on health. We then embed the model in a general-equilibrium context to show that using information on aggregate fish catches of the two types of fish can identify the sign of the effects of each fish type on cognition if fish markets are local.

We assume that a household with a very young child jointly consumes three foods that are imperfect substitutes in the utility function *U* – low-mercury and high-mercury fish (*L* and *H*, respectively) as well as another food *C*. Both types of fish are produced locally, and not tradeable, while the third consumption good *C* (e.g, beef) is a tradeable good whose price does not depend on the supply of local fish. The household also derives utility from the cognitive skill *s* of its single child. The utility function is:

(1) $$U = u(L, H, C) + v(s)$$

Fish are "brain food" and cognitive skill is a Cobb-Douglas function of the two types of fish and other tradable inputs such as books, school tuition, represented by *x*:

(2) $$s = L^{\gamma} H^{\delta} x^{\beta}.$$

The medical literature suggests that $\gamma > 0$ and $\delta < 0$ - low mercury fish increases cognitive skill because of omega-3, but mercury-laden fish, which also contain omega-3, block cognitive development among young children, it is poison. The household is unaware of the differential effects of the two types of fish, and just believes that any fish is "brain food":

(3) $$s = s(L + H, x), s_1, s_2 > 0$$

Child height, to which the household is indifferent, is also a function of all three foods. We assume innocuously and for simplicity that the three foods, which are protein-rich, have identical effects on height, where $0 < \varepsilon + \varepsilon + \varepsilon < 1$, as there is no medical literature indicating that omega-3 enhances physical growth or that mercury inhibits physical growth:

(4) $$h = H^{\varepsilon} L^{\varepsilon} C^{\varepsilon} .$$

The household is a price-taker with exogenously-given income Y, and its budget constraint is

(5) $$Y = p_H H + p_L L + p_x x + C$$

The household maximizes (1) subject to (3) and (5). The price of the non-local *C*-good is the numeraire.

We now consider an experiment in which we randomly subsidize the price of low-mercury fish, with the price of high-mercury fish held constant (or, equally, prices of *H* are equal level in treatment and control groups) and assess the effect on cognitive skill. Given the solution to the household's maximization program, it is easy to show that the elasticity of cognitive skill with respect to a change in p_L , $\eta_{s\,p_L}$, is

(6) $$\eta_{s\,p_L} = \gamma \eta_{L\,p_L} + \delta \eta_{H\,p_L} + \beta \eta_{xp_L} < 0 .$$

A reduction in the price of low-mercury fish unambiguously increases cognitive skill, if the medical literature is correct. However, as can be seen in (6), this is due both to the increase in the consumption of low-mercury (good) fish and to the reduction in high-mercury fish, which is a substitute (we assume that the effect on the *x*-good is second-order). The sign of (6) therefore is not indicative of the individual effects of high-and low-mercury fish. Expression (6) can be negative as long as $\delta \eta_{Hp_L} < \gamma \eta_{Lp_L}$; alternatively (6) can be negative if both types of fish have negative effects on skill and $\gamma \eta_{Lp_L} < \delta \eta_{Hp_L}$; or (6) can be negative if $\delta = 0$ and $\gamma < 0$. An experiment subsidizing either type of fish consumption thus does not identify the signs of either γ or δ . The experimental result cannot therefore support a warning about the adverse effects of consuming high-mercury fish by pregnant mothers or young children, it only supports a conclusion that low-mercury fish is better brain food than high-mercury fish.

Now assume we have information on the aggregate local supply (catches) of low- and high-mercury fish, K_L and K_H, respectively, and that there is an increase in K_L. As indicated in Figure 4 given a fixed supply of high-mercury fish K_H, and a downward-sloping demand curve for *L*, an increase in K_L lowers the price of L, p_L, so that all of the additional K_L is consumed. At the same time, the decline in p_L shifts the demand curve for high-mercury fish downward, given that *H* and *L* are substitutes, such that in the new equilibrium all of the (unchanged) high-mercury fish catch is consumed as before.

The effect on cognitive skill at the household level from an increase in the low-mercury catch, for given high-mercury catch, will depend on by how much the aggregate increase in K_L reduces p_L and on $\eta_{L p_L}$. In elasticity terms, the effect of an increase in K_L on *s* for given fixed K_H is

(7) $$\eta_{sK_L} = \gamma \eta_{LK_L} > 0 ,$$

from which we can see that the sign of γ is identified, given that $\eta_{LK_L} > 0$. Similarly, if there is an increase in the supply of high-mercury fish, for given low-mercury catch, the sign of δ is identified:

(8) $$\eta_{sK_H} = \delta \eta_{HK_H} < 0 ,$$

if $\delta < 0$.

The aggregate increase in K_L, for given K_H, which reduces the price of both *H* and *L*, would also reduce the consumption of the substitute food *C* whose price, by the tradability assumption, is unaffected by the local supply of fish. The effect on child height, in elasticity terms, is given by

$$\eta_{hK_L} = \varepsilon\left(\eta_{LK_L} + \eta_{CK_L}\right), \tag{9}$$

from which it can be seen that the height effect from the *ceteris paribus* increase in the supply of low-mercury fish may be small even if ε is large when fish and other protein-rich foods are strong substitutes, since η_{LK_L} and η_{cK_L} are of opposite sign.

The aggregate fish catch comparative static results assume that variations in K_L and K_H move independently of income Y. In the absence of perfect controls for income, a key identification assumption for identifying the effects of the consumption of fish types on cognition using aggregate catch data is that *Y* and K_L and K_H are not correlated. This is because *Y* can have a direct effect on *s* by altering the amount of *x*.[5] In the Colombia case, even in coastal municipalities less than two percent of households earn a living from fishing, so there is no significant direct casual effect of fish supplies on earned income. However, macro shocks to income might change the demand for fish, and aggregate fish supply may be responsive to income. What is required for identification is a set of variables that affects the supplies of fish of the two type that are not correlated with income and do not directly affect cognitive skill net of fish supplies. We discuss our identification strategy in the next section.

[5] In an RCT, randomization of the fish price by design would eliminate the correlation between the treatment price and income.

Note that the effect on *s* or height from an increase in Y, given fixed supplies of fish, does not identify the conventional income effect, which is for a fixed set of prices. This is because, as seen in Figure 5 where K_F is the aggregate catch of all fish and p_F is the equilibrium price of fish, if there is an increase in demand for fish due to the rise in income, the price of fish would increase so that supply and demand are equated. The consumption of total fish would thus stay the same, given the fixed fish catch, but there would be less resources for other inputs compared to the fixed-price case.

III. Colombia Coastal Fish Supply and Climate Variability

Colombia has both Atlantic and Pacific coasts: 47 municipalities have coastline (the municipality is the lowest administrative division in Colombia). The website **www.seaaroundus.org** (Lindop *et al.*, 2015; and Wielgus *et al.*, 2010) provides the total amount of fish caught by year and by ocean off the coasts of Colombia for the period 1950-2014.[6] The data categorize fish by whether they are commercially fished ("industrial"), mainly for export, and "artisanal" and "subsistence" fish that are consumed locally. It is the latter two categories of fish that matter in determining the elevated consumption of fish by coastal populations. Figure 6 displays the four-year moving averages of the total catches of locally-consumed fish (artisanal and subsistence) by year from 1950 to 2014 and by ocean (Atlantic and Pacific).[7] As can be seen,

[6] The general description of these data is found in Zeller *et al.* (2016). The data augments FAO reported fish landings by the inclusion of reconstructed data or previously unreported catches and major discards. The reconstructed catch series for the period 1950-2010 for Colombia are 2.3 times the FAO catch reports for the same period (Lindop *et al.*, 2015).

[7] As discussed below, we will be measuring the supply of low- and high-mercury fish in the four-year period beginning at conception to capture exposure to healthy and unhealthy fish in early childhood for cohorts of Colombian children. Thus, all of our measures are based on four-year averages.

on both coasts the amount of fish caught varies substantially by year, with fluctuations on the Pacific coast being especially pronounced.

The amounts of fish caught also vary substantially by species. Colombia has one of the most diverse marine ecosystems, with 104 species represented in the aggregate catch data. Species of fish matter for studying the effects of fish consumption on human development because fish differ, as discussed, in the amounts of methyl mercury they contain. The second column of Tables 1A and 1B reports the average mercury concentration for each of the 43 species of fish that have been available for consumption on the two Colombia coasts. The lowest mercury concentration is found in the pink conch (0.009 milligrams per kilogram). The highest mercury concentration is 1.77 milligrams per kilogram and it is found in hound-sharks and smooth-hounds, with many levels of mercury concentration represented across all of the species.

Importantly, two of the elements in high concentrations in fish that affect brain development - Docosahexaenoic acid or DHA (one of the two beneficial omega-3 fatty acids in fish) and methylmercury - appear to be distributed randomly across the fish species consumed on the Colombia coasts with respect to each other. Across the 43 species of non-industrial fish that are consumed on the coasts, the correlation between DHA and mercury concentration is a statistically insignificant 0.093. Figure 7 displays the scatterplot for DHA and mercury. We thus categorize the fish species solely on the basis of mercury content.

Based on the recommendation of the Natural Resource Defense Council (www.nrdc.org), which suggests eating less than six serving per month of fish species with more than 0.165 parts of mercury per million, we used the information on fish-specific mercury concentrations to separate the total fish catch into high-mercury and low-mercury catches in accord with the model. Because of the lack of correlation between mercury content and omega-3, low-mercury and high-mercury fish thus have on average the same beneficial brain development ingredients. Figure 8 displays total catch sizes by year and by coast from 1950-2014 for the high- and low-mercury fish species and Figure 9 plots the average mercury content of the local fish catch by coast over the same period.

The substantial variability in the size of the fish catches by mercury concentration across years exhibited in Figure 8 is not random. One potential factor is variation in climate, whose mechanisms for the Pacific have been both modeled and tested in the climate science literature. In the Pacific, changes in sea surface temperatures (SSTs) affect the supply of oceanic nutrients due to shifts in trade winds, which have been categorized into two classes by climate scientists. El Niño occurs when the trade winds become weak. Trade winds are supposed to move warm water from the Eastern to the Western Pacific. When trade winds are weak, warm water remains in the Pacific. La Niña occurs when the trade winds are strong. Then, the warm water of the Eastern Pacific is moved in large quantities to the Western Pacific. This climate variation, as we will see, affects the composition of fish.

Satellites have been able to measure sea surface phytoplankton, the base of the food web, for the last 15 years. Reduced upwelling of nutrient phytoplankton rich cold water – which occur, for example, during El Niño in the Pacific- causes species either to migrate or to move deeper into the sea. The temperature of the sea is also affected by the occurrence of oceanic waterfronts where currents of different temperatures encounter and generate phytoplankton-rich waters, attracting fish.

An important reason why variation in SSTs can affect the supplies of fish by species is based on the fact that fish are ectotherms; they cannot regulate their body temperature like humans. And fish species differ in their ability to thrive and survive by water temperature. The third and fourth columns of Tables 1A and 1B report the sea temperature range for which each fish species is observed in the coastal waters of Colombia (Kaschner *et al*., 2016). These temperature intervals also differ significantly by fish species. For example, while flatfish (a low-mercury fish) are never seen in waters colder than 26.4 degrees Celsius, snappers (a high-mercury fish) can survive in waters as cold as 20.5 degrees. The most important implication of this variation is that different species can live in different sea surface temperatures but a given species would have to migrate if the temperature of the sea changes. Hence, changes in SSTs potentially cause changes in the composition of fish species in different oceans.

SSTs also vary substantially across years. In the period 2002-2011, the average minimum SST in the Pacific was 18 degrees and the average maximum was 29.1 degrees Celsius, the analogous figures for the Atlantic were 22.9 and 29.8 (Cherrington *et al*., 2011). These temperature bounds compare with the average minimums and maximums for the fish species of 21.4 and 31.9 degrees, respectively.

Climate scientists define El Niño and La Niña episodes in the Pacific based on counts of SST anomalies, where an anomaly is defined to occur when there is any change in temperature that exceeds (falls below) 0.5 (-0.5) degrees Celsius. For the Atlantic an anomaly is defined as a change in SST below or above 0.18 degrees, where the number 0.18 is the value of the standard deviation in the full time series of Atlantic SST. These anomalies occur frequently on each coast. Figure 10 displays the number of months in a year where four-year moving average of temperature deviations centered around each month exceeded the anomaly threshold by year and Colombian coast over the period 1950-2010. The actual temperature changes in these anomalous periods often exceeds the thresholds by a considerable margin. Figure 11 plots the four-year moving averages of the deviations in temperatures for both negative and positive SST anomalies by year and by Colombian coast from 1950-2010. For the Pacific coast, for example, the averaged mean temperature deviation reached or exceeded one degree in absolute value in five of the anomalous episodes over the 60-year period.

Can the variation in SSTs help explain the variation in fish species, and thus the availability of healthy (low *MeHg*) and unhealthy (high -*MeHg*) fish, across years along the Colombian coasts? There are many factors that affect the dynamics of fish catches. For example, overfishing, which is likely responsible for the two large peaks in the total fish catch observed in Figure 6 for the Pacific Coast. SST variation, as noted, may also play a role, but as far as we know there is no study that relates SST variation to the species composition of fish catches that is implied by the measured heterogeneity among fish species in livable temperature ranges.

Table 2 reports regression estimates of the effects of the four SST variation measures displayed in Figures 10 and 11 on total fish catches and on low- and high-mercury fish species catch sizes. The four independent variables are the number of months in the year above and below the coast-specific anomaly threshold and the mean positive and negative temperature changes in the anomalous months. Because the thresholds differ by ocean, we allow the effect of each of the four measures on the fish catch dependent variables to vary by coast. We use observations from 1950 to 1998, the years in which the cohorts of Colombians for whom we have outcome measures were conceived.

The set of eight SST variables explains over 30% of the variation in total catch size over the 48-year period and more than a third of the variation in the catch sizes of the high-mercury species. The incidence of colder temperatures appears to be the most important factor affecting the sizes of the fish catches overall and by species, with the effect of opposite signs across the coasts – more and stronger negative temperature deviations evidently lower fish catches on the

Pacific Coast but raise them on the Atlantic Coast. Of the positive deviations in temperature, only the size of those anomalies on the Atlantic Coast matter and only for the size of the catches of high-*Hg* fish species, with greater positive deviations increasing catch size only for the high-mercury fish. This latter result means that variations in low- and high-mercury fish species catch sizes are not perfectly correlated, which is helpful for identifying the separate effects of the two types of fish catches on cognitive outcomes.

Climate variation is not only associated with variability in the stock of fish along the Colombian coastlines. Unusual changes in trade winds (in the Pacific) also affect the amount of rainfall, and rainfall may affect incomes in Colombia, where a not insignificant fraction of the labor force is engaged in agriculture (17% in 2011). In particular, La Niña generates above-average rains while El Niño generates lower-levels of rainfall and even droughts in most parts of Colombian territory. The Ocean Niño Index (ONI) model defines an el Niño (la Niña) episode event as a period with at least five consecutive anomalous warm (cold) months in the sea surface of the equatorial Pacific (a change above 0.5 degrees Celsius). Using annual rainfall data from rain stations on both coasts in Colombia from 1963-2015 and information on the Pacific SSTs we can assess how well the ONI model performs and compare the performance of the ONI variables with those we have used to predict fish catch variation.[8]

In the first column of Table 3 we report the estimates of the effects of the two ONI variables on Colombian coastal rainfall. The two ONI variables explain almost 90% of rainfall variation and the coefficient signs are in accord with the ONI model, with unusually cold months predicting positive rainfall and unusually warm months predicting less rainfall. However, as

[8] 1963 is chosen as the initial year because that is the year in which there were at least five municipalities with rainfall data/stations on the Pacific coast. In the Appendix, we describe the coastal rainfall data we use in more detail.

Table 3 also shows in the second column, just the numbers of anomalous warm (cold) months in the Pacific in a given year, among the set of variables we used to predict fish catches, also predict well rainfall that year, with an R-squared equal to that of the ONI model. Note that while the ONI model, or SST anomalies, predict rainfall, there is no underlying climate model that indicates that SSTs cause rainfall variation. The ocean temperature and rainfall variables might be jointly affected by atmospheric variables.

Because climate variability is associated with both coastal rainfall and fish supply composition, to identify the effects of the time-series variation in fish consumption by *MeHg* content on cognitive development we will take into account rainfall variation when we estimate the effects of fish catch variation around the birth of child. This is because rainfall may affect income in Colombia. Using annual data by state for the period 1979-2015, we regressed the log of real GDP on rainfall using year and state fixed effects. Table 4 reports the fixed effects estimates. Based on the wild-bootstrapped standard error, the rainfall coefficient is positive and weakly statistically significant (one-tailed test) at the 0.06 level.

IV. Fish Consumption and the Coastline

To estimate the effects of the supply of high- and low-*MeHg* fish around the time of birth on cognitive development we want to focus on a population for which fish is a significant component of the diet of young children. As was seen in Figure 1 based on the 2010 DHS data, even within income groups fish is much more likely to be fed to children living in coastal municipalities compared with the rest of Colombia. As noted, the Colombian DHS of 2010 records whether a child less than 24 months old was given a particular food the day before the survey, including fish, meats, and eggs. The DHS also identifies the municipality of birth for the child so that we are able to both identify coastal communities and merge to the DHS data additional characteristics of municipalities besides the proximity to the coast of a child in her first years of life. The DHS also provides information on the characteristics of the mother and the household in addition to the household wealth categorical variables.

In the first column of Table 5 we show that the estimated higher propensity to feed fish to young children aged 9 to 24 months in coastal compared with non-coastal communities indicated in Figure 1 is robust to a large set of child, maternal, household and municipality-level controls.[9] The point estimate indicates that net of the controls, children on the Colombian coasts are twice as likely to be fed fish between the ages of 9 and 24 months as children born elsewhere in Colombia, given the mean values of the variables (reported at the bottom of the table). Moreover, as shown in the second column of the table, *within* coastal municipalities children are significantly more likely to be fed fish the larger the fraction of the municipality border that is coastline. The sea-access coefficient is significant at the 0.04 level with bootstrapped standard errors clustered at the municipality level. The point estimate indicates that, net of the controls, 3.8% of children aged 9 to 24 months are fed fish in the most land-locked coastal municipalities (4% coastline) compared with 96% if the municipality is an island.[10] As Table 6 shows, the closest protein substitute for fish is evidently meat, as young children in a coastal municipality with more coastline are significantly less likely to be fed meat, but are more likely to be fed eggs, with only the meat coefficient statistically significant. Total animal protein consumption – meat plus eggs - however, is evidently unrelated to coastline size.

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[9] The control variables include household wealth, the child's exact age in months, gender, race, urban location, number of persons and children under five years old in the household, the mother's education and age, the average altitude in meters above sea level, an index of the quality of the soil for agriculture, whether there is maritime port, average yearly precipitation in the period 1980-2010, founding year of the municipality, and the volume of water that flows in rivers and lakes in 2000 in cubic meters.

[10] Two of the 47 coastal municipalities are islands.

The results in Table 5 are not surprising. As shown in Figures 12 and 13 the price of fish is substantially lower in coastal municipalities than elsewhere while the price of meat is substantially higher. Of course, municipalities differ by more than food prices. We want to use variation in the availability of fish for a given municipality over time, on the presumption that local fish supplies affect local prices. As shown in section III, coastal fish stocks vary substantially over time and systematically with variations in ocean sea surface temperatures.

A key assumption of the model is that the increases in local fish supply lower local fish prices. To test this, we obtained an annual aggregate time-series of a fish price index for four cities close to the sea (Barranquilla, Cartagena and Monteria are coastal cities in the Atlantic; Cali is less than 100 kilometers away from the Pacific) for the years 1999-2013. We thus can estimate the effects of variation in the total fish catches by coast on the local fish price.

Figure 14 plots the log deviations in the real coastal-city fish price against the log-deviations in the aggregate coastal fish catches along with the fitted regression line. As can be seen, the relationship between coastal fish catches and the fish price is negative (it is also statistically significant) for these coastal cities. Of course, the supply of fish on the coast may reflect the local demand for fish, so the slope may underestimate the true fish price demand elasticity. To estimate the causal effect of fish supply on price we use the four coast-specific SST variables listed in Table 2 as instruments and estimate the relationship between the local fish catches and local fish prices by IV.

Table 7 reports the city fixed effects (FE) and IV-FE estimates of the effects of the log total coastal fish catch on the log of the real price of fish (pesos per 500 grams) in the four cities for the period 1999-2013. For the latter estimates we allowed the set of four coastal SST variables to differ by coast. We also include coastal annual rainfall in the second-stage specification, which may affect fish demand, and, as was shown, is correlated with the SST instruments and with real GDP. Both the FE and the IV-FE fish supply coefficients are statistically significant and indicate that increases in the supply of local fish lower the local price of fish. Local rainfall does not appear, however, to affect the local fish price, net of the supply of fish. The diagnostic statistics indicate that the IV-FE point estimate, which is twice as large in absolute values as the FE estimate, is well-identified. The IV-FE point estimate indicates that the fish price demand elasticity is -0.11.

V. Identification Strategy and Econometric Model

Based on the empirical findings that (a) a large fraction of children in coastal municipalities are fed fish, (b) within coastal communities the fraction of the border that is coastline is significantly and positively associated with increased fish consumption among children, (c) the coastal fish price is responsive to coastal fish supplies on the relevant coasts, and (d) fish catches are significantly affected by changes in coast SSTs, our identification strategy for estimating the early-life causal effects of the consumption of low- and high-*MeHg* fish by pregnant mothers and young children on children's skill outcomes *s* (test scores, schooling, occupation classification) later in life is to estimate the following econometric model on cohorts of children born in coastal municipalities using the SST variables as instruments for the fish catches:

$$s_{i,m,t} = \alpha c_m K_{L,t} + \beta c_m K_{H,t} + \rho R_{m,t} + d_m + d_t + \xi_{i,m,t}, \quad (10)$$

where *i* is an individual, *m* is her municipality of birth and *t* her cohort. All right hand side cohort-specific variables are defined as four-year averages enclosing the year before birth and three years of life after birth ("around birth"). c_m is the fraction of the municipality border that is coastline, $K_{L,t}$ and $K_{H,t}$ are, respectively, the sizes of low- and high-mercury fish catches on the relevant coast around birth for the cohort, and $R_{m,t}$ is rainfall in municipality *m* around birth for the cohort. d_m and d_t are coastal municipality and cohort fixed effects, the latter absorbing all cohort-specific Colombia-wide market prices and macro shocks to income at the time of birth.

The IV instruments are the set of variables characterizing the anomalies in sea surface temperature (SST) around birth that we found to predict fish catches by *Hg* content: the number of four-month moving averages centered around each month in the year above (below) the anomaly threshold, +0.5 (-0.5) Celsius in the Pacific and +0.18 (-0.18) Celsius in the Caribbean, and the mean of the positive (negative) temperature changes that were anomalous during the corresponding four-month moving averages that year. Because the thresholds vary by ocean, we interact each of the SST anomaly variables with an indicator for whether it is from Atlantic coast. All first-stage variables are also interacted with the fraction of the municipality border that is coastline. Thus, the key exclusion restriction is that, conditional on rainfall and municipality and cohort fixed effects, the set of anomalies in ocean-specific SSTs affect skill outcomes only through their effects on the variation in the fish catches. Based on the medical literature findings and our equilibrium model, we expect that $\alpha > 0$ and $\beta < 0$.

VI. Achievement Test Scores at Age 17 and Fish Species Availability at Birth

In this section we use government administrative records containing achievement test scores from exams (SABER 11) taken by all exiting high school seniors in Colombia in the years 1980 through 2015 (with the exception of the year 1994, which is officially lost) to estimate the effects of early childhood fish consumption on later-life school achievement. We examine test-scores for both the math and verbal components of the test, standardizing results by year. The records identify the name of the municipality and school where the exams took place. A limitation is that they do not contain the municipality of birth or the age of the student. Given these data restrictions, we assume that the municipality where the exam was taken is the same as the municipality of birth and that the year of birth is the year of the exam minus 17 (which is the average age when students take the exam).[11] Thus, we have 34 birth-cohorts, with birth years corresponding to the period 1963 through 1998. We restrict our analysis of these data to students in the 47 coastal municipalities. Using the municipality and cohort information of the exam records, we merged the relevant four-year average coastal fish catch and SST measures so that they corresponded to the four-year period following the conception of each student – covering the nine months *in utero* plus the first three years post-birth - resulting in a sample of 1,184,817 test records with fish "exposure" information.

The first column of Table 8 reports the year and municipality fixed effects estimate of the effect of total local fish catch size around the time of the birth of each cohort on their verbal test score at the time of high school graduation. This is the net effect of consuming both high- and low-mercury fish, and the coefficient is negative and statistically significant. However, when we implement the IV estimation method, the coefficient is cut by a third and is further reduced when we add rainfall. The diagnostic statistics indicate passage of both the under-identification and over-identification tests. These results suggest that the average effect of the elevated fish consumption on the coast on skill attainment is insignificant.

[11]According to the census of 1993, 75.9% of individuals 17 years old residing in coastal municipalities were born in their current municipality. In section VIII below, where we use census data, we find that the estimates for populations residing in coastal municipalities are similar to those obtained from populations born in coastal municipalities but whose current residence may be different.

However, when we decompose the fish catches by mercury content we see that the composition of fish species matters and the results are robust to estimation method and specification - a higher average catch size of low-mercury fish in the first four-years of life, given the catch size of high-mercury fish, significantly increases verbal test scores at age 17, while for a given low-mercury catch size, an increase in the catch size of high-mercury fish significantly lowers the verbal test score. Again, the diagnostic statistics are consistent with the assumptions of the econometric model. The IV-FE point estimates from the complete specification including rainfall around birth in the last column of Table 8 indicate that a one standard deviation increase in low-(high-) mercury fish at that time increases (decreases) the verbal test score by 0.05 (0.10) standard deviations at age 17.

The estimate of the effect of early-age rainfall on the verbal test score when the model is estimated using IV-FE is also negative and statistically significant. Given that rainfall evidently increases income, this suggests that for given supplies of the two fish types, the effect of higher incomes is to raise the price of fish and to shift the composition of the diet to (tradable) foods with less "brain" effects and whose prices are unaffected by local weather.

The results for math test scores, reported in Table 9, are similar to those for verbal test scores – the net effect in Colombia of overall greater fish availability on the coast around the time a child is born on later-life scholastic achievement in mathematics is insignificant. However, increases in the availability of high-*Hg* fish around the time of birth, given the supply of low-*Hg* fish, lower math test scores significantly. The effect of a higher supply of low-*Hg* fish, given high-*Hg* fish availability, is positively related to the math test score just as it was for the verbal test score, but the estimate is smaller and only marginally significant (0.12 level, two-tailed test). The FE-IV point estimates indicate that a one standard deviation increase in the low-mercury fish catch in the first four-years of life *ceteris paribus* lowers the math test score by 0.075 standard deviations, while a similarly-defined increase in the low-*Hg* fish supply at that early stage of life increases the math test score by only 0.02 standard deviations. Finally, parallel to the result for verbal test scores, higher rainfall around the time of birth is associated with lower math scores, but the rainfall estimate for math test performance is statistically insignificant.

VII. Placebo and Robustness Tests

The estimates in Tables 8 and 9 indicating that the composition of fish species availability with respect to mercury content around birth affects both verbal and math test scores at age 17 are consistent with the medical literature and folklore that fish is indeed "brain" food: fish, unlike other foods, contain specific elements that enhance early-age cognitive development but also block such development (*MeHg*) as a poison. In this section, we assess (a) whether our results are spurious with a placebo test that estimates the effects of fish catch species composition around birth on adult height; (b) whether early-in-life fish catch sizes matter more for cognitive development than do fish catch variations occurring later in the life cycle, as suggested by the medical literature on child development; and (c) whether our results are biased by the omission of the consideration of another Colombian food staple – rice – which may also contain elevated levels of *Hg*.

<u>Fish species availability around birth and adult height</u>. We employ the same econometric model (10) and data on fish catches and rainfall to estimate the effects of fish species availability around birth on height. Fish is a high protein food, and the medical literature suggests that the early-life consumption of protein affects physical growth. Thus, we would expect that the greater total availability (lower price) of fish around birth would increase height. However, as far as we

know, there is no medical literature suggesting that mercury affects physical development, and thus the species composition of fish catches should be unimportant in determining height later in life. If we do find that composition matters for height, that would call into question our interpretation of our findings on test scores as reflecting the special cognitive properties of fish.

We carry out our analysis of height using another large administrative database, the *Registraduría Nacional del Estado Civil*. By law, when a Colombian resident turns 18 years old, she must register as a citizen and obtain an identity card. Colombian identity cards have the municipality of birth, the date of birth, the municipality of registry, the date of registry (87.9% of Colombians register before 21 years of age; 48% at age 18), the gender, and the height of the citizen. We obtained these identity-card records for people born between 1951 and 1997; the size of each cohort varies between 154,246 (1951) and 557,761 (1995) and the total number of records is 18,519,896. We again restrict the sample to citizens born in the 47 coastal municipalities, but we were only able to obtain the records of those born on the coast and who also registered in coastal municipalities (permanent coastal residents), resulting in a sample size of 1,842,224 citizens.[12]

Table 10 reports the estimates of the effects of total and species-specific fish catches in the first four years of life on adult height, using the same instruments and specifications as were used for test scores. The FE-IV results for height are as expected and are in contrast to those obtained for the cognitive assessments – increases in the total amount of fish caught around the time of birth significantly increase height (third column), but there is no negative effect on height

[12] According to the 1993 census, 73.4% of people aged 18 and 21 years old and residing on the coasts are permanent residents. We show below that this restriction on later-life residence has little effect on estimates of early-life fish supply variation using census data.

if the catch size of high-*MeHg* fish is higher relative to the catch size of low-*MeHg* fish; total fish supply around birth but not fish species composition affect height in accord with the existing medical literature. And, increases in average rainfall in the first four-years of life increase height, consistent with rainfall increasing incomes and with the universal findings that children from lower-income households exhibit stunting.

Fish species availability around birth and at later ages and test scores at age 17. The medical literature indicates that methyl-mercury inhibits intellectual development at very young ages, which is why we employed fish catch variation in the four years after conception (one year before birth and three years after birth). To further assess the credibility of our results, we add to the specification (10) the catch sizes for the two types of fish defined by *Hg* content when the cohorts were also at 7-10 years of age, extending the set of instruments to include SST anomalies at those later ages. Thus, we are running a horse race between the early- and later-age exposures to fish supplies with differing mercury content on test scores.

Table 11 reports the estimates from the extended specification with both early- and late-stage fish catches for verbal test scores. The statistically-preferred IV-FE estimates of the effects of the total fish catch at early ages, in the third column, are positive and statistically insignificant, the same result we found when the later-age total fish catch is excluded (Table 8). The later-age total fish catch coefficient is also statistically insignificant. More importantly, in the last column of the table, we replicate the results from Table 8 - higher low-mercury fish catch sizes in the first four-years of life increase verbal test performance, while increases in the catches of high-mercury fish in the same period lower the verbal test score. Both results remain statistically significant, and the coefficient sizes are similar in magnitude to those in Table 8, with the low-*Hg* coefficient slightly larger and the high-*Hg* coefficient slightly smaller in absolute value.

Moreover, the individual coefficients for the later-age fish catches are statistically not distinguishable from zero and jointly insignificant. This result confirms what the medical literature evidence suggests, that early-age exposure, when the brain is developing, to the good and bad attributes of fish causally affect cognitive development, but not later-age exposure.

The one departure from the results obtained using the more parsimonious specification (based on the prevailing medical literature evidence) is that the coefficient on rainfall at birth, while still negative, is now statistically insignificant, while the rainfall coefficient associated with ages 7-10 is negative and statistically significant. The rainfall results thus appear to be less robust than the fish catch findings.

The estimates from the extended specification for the determinants of math test performance, reported in Table 12, are less informative. While the sign patterns of the IV-FE coefficients for around-birth total fish catch (column three) and the fish catches for the two types of fish (column six) are the same as those obtained from the parsimonious specification, none of the early-stage coefficients are statistically significant. Like the results in Table 11, however, the later-age fish catch coefficients are also not statistically significant. Thus, we find no evidence that the later-age availabilities of low- and high-mercury fish, conditional on early-age exposures to fish availability, have any effect on scholastic achievement at age 17.

Rice and mercury. A staple of the Colombian diet is rice. There is growing evidence that rice is also laden with mercury (Liu *et al*., 2019), although we know of no evidence of this for the specific rice varieties consumed in Colombia. However, a key assumption of the model is that non-fish alternative foods are tradeable, and tradeable food price variation is captured by the year fixed effects. The questions is whether the tradability assumption holds for this other potential source of mercury consumption. Colombia imports rice, with imports accounting for

15% of total rice consumption. We obtained the annual retail price series for rice consumed in Colombia and the international rice price time-series for the years 1996-2019 as well as the annual value of domestic rice production for the same period to see if the domestic price of rice is anchored by the international price, rather than by domestic supply or demand.

The first column of Table 13 reports the estimates from a regression of the log of the real domestic rice price on the log of the international price. The coefficient is positive and highly significant, and the variation in the log of the international price explains more than 37% of the log-variation in the domestic price. Moreover, in column two, we see that net of the international price, variation in the domestic production of rice has no effect on the domestic rice price. Thus, we are confident that the year fixed effects absorb the price of rice along with other Colombian tradable commodities.

VIII. Fish Species Supply Around Birth and Adult Schooling Attainment and Occupation

The estimates in Tables 8 and 9 indicate that the increased availability of high- and low-mercury fish in the first four years of life have significant and opposite effects on test score performance at age 17, with the higher availability of mercury-laden fish around birth significantly lowering test scores and higher supplies of low-mercury fish increasing scores. In this section we use data from the Colombia Census of 1993 to estimate the effects of the composition of around-birth coastal fish catches on adult schooling attainment and occupation for persons born in coastal provinces.

The 1993 census is the most recent Colombian census available to researchers that provides information on municipality of birth and residence and schooling and occupation.[13] It has two advantages over the administrative records we used to assess the effects of early-stage fish catches on test scores and height. First, the census provides information on age, gender and race. Second, we do not have to restrict the sample of those born on the coast to those who are also residing on the coast as adults; that is, we can allow out-migration to any type of municipality. The census data thus permits comparisons of estimates obtained from the population of permanent coastal residents, whose test and height records we used in the previous analyses, with estimates based on the population who were born on the coast regardless of subsequent place of residence. This will allow us to assess the selectivity bias, if any, from the geographic restriction of the heights and test scores data bases. A limitation from using the census of 1993 is that we would lose a large fraction of cohorts (years) if we include rainfall in the specification because, as noted, there is insufficient rainfall data prior to 1963 due to the lack of rain stations. Because identification relies on time-series variation, we thus exclude rainfall. Our test score results on fish catch effects appear to have been strengthened by the inclusion of the rainfall variable, so we think the census-based estimates are conservative.

We examine the schooling and occupational outcomes for individuals born in coastal municipalities who were aged 21 to 40 in 1993 and who were thus born in years 1953-1972.[14] Using the school attainment information from the census, we created indicator variables for whether the individual had obtained any post-secondary education and whether the individual

[13] The 2005 Census does not provide municipality of birth or residence. The 2018 Census did not elicit information on schooling or occupation.
[14] We do not have time series of rainfall for most of these years because of the absence of rain stations in Pacific coastal municipalities, as indicated in the Appendix.

was working in a blue-collar occupation, based on the categories ‘working class,’ ‘agricultural day laborer’ or ‘domestic employee.’ 13.8% of this coast-born population in 1993 had achieved some post-secondary schooling and 41.5% were working blue-collar occupations. We merged the census data, for the 812,128 individuals with valid schooling information and 826,852 individuals with valid occupational data who were born in coastal municipalities, with our fish catch and SST variables corresponding to their four years of life post-conception.

We expect, based on the test score results, that total fish catches around birth should have no effect on post-secondary schooling attainment, while the elevated catches of high-(low-) mercury fish should lower (increase) the likelihood of obtaining schooling beyond high school. With respect to occupation, given our finding that the total fish catch increased height, the Roy-model of occupation selection based on comparative advantage would predict both that those born in high total-catch years and in years with greater relative high-*Hg* fish availability would be more likely to be engaged in brawn-based, blue collar occupations (Pitt *et al*., 2012).

The FE-IV schooling estimates, reported in columns two and four in Table 14, conform to the findings for the test scores: while there is no effect of total catch size around birth on the likelihood of going on to achieve some post-secondary schooling, increases in the early-life catch size of low-*MeHg* fish increase that likelihood while higher levels of high-*Hg* fish catch sizes in that period lower the likelihood, the former statistically significant at the 0.01 level and the latter at the 0.10 level, two-tailed test. The point estimates indicate that, for a person born in a coastal municipality with an average fraction of border that is coastline (0.3), a one standard-deviation increase in the size of the average catches for low-*Hg* fish in the first four years of life, given the high-*Hg* catch size, increases the likelihood of attaining some post-secondary education by 8.0%, while a one standard-deviation in the high-*Hg* fish catch *ceteris paribus* lowers that probability by 6.7%.

The FE-IV estimates of around-birth fish catches on adult occupation, in Table 15, also conform to the height and test score findings and the operation of Roy selection. The greater total availability of fish in the first four years of life for those born on the coast, which we found to increase their adult height, increases significantly the likelihood of their being in a blue-collar occupation as an adult. The point estimate indicates that a one standard-deviation in the average total fish catch size in the first four years of life increases the probability of being a blue-collar worker as an adult by a statistically significant 2.7%. Moreover, if there is an increase in the catch size of high-*MeHg* fish by one standard deviation early in life, the probability of being in a blue-collar occupation later in life rises by a statistically significant 4.3%. The effect of an increase in low-*MeHg* fish around birth, as expected given the test score findings, decreases the probability of being a manual, blue-collar worker by 2.2%, but the estimate is only marginally statistically significant.

The census-based schooling attainment and occupation estimates were obtained from populations born in coastal communities but whose residence as adults was unrestricted. To assess whether restricting the population to those both born and also continuing to reside in coastal municipalities in 1993, corresponding to the restriction placed on the test score and height databases, affects our findings, we estimated the effects of the around-birth fish catches on the schooling and occupation variables on the restricted sample of permanent coastal stayers. The estimates for schooling and occupations are reported in Tables A2 and A3, respectively, in the appendix. The estimates are indistinguishable from those obtained from the unrestricted sample.

Thus, we do not think the restriction on mobility has biased significantly the test score and height estimates and thus inferences about the special properties, good and bad, of fish as brain food.

IX. Conclusion

Production technologies interact with and transform the environment. The burning of fossil fuels to produce electricity generates acid rain. The emission of greenhouse gasses to facilitate transportation, for example, contributes to global warming. The use of the gold-mercury amalgam since Spanish conquistadors and coal burning since the Industrial Revolution deposited large quantities of mercury, an element that cannot be destroyed, in soils, rivers and oceans.

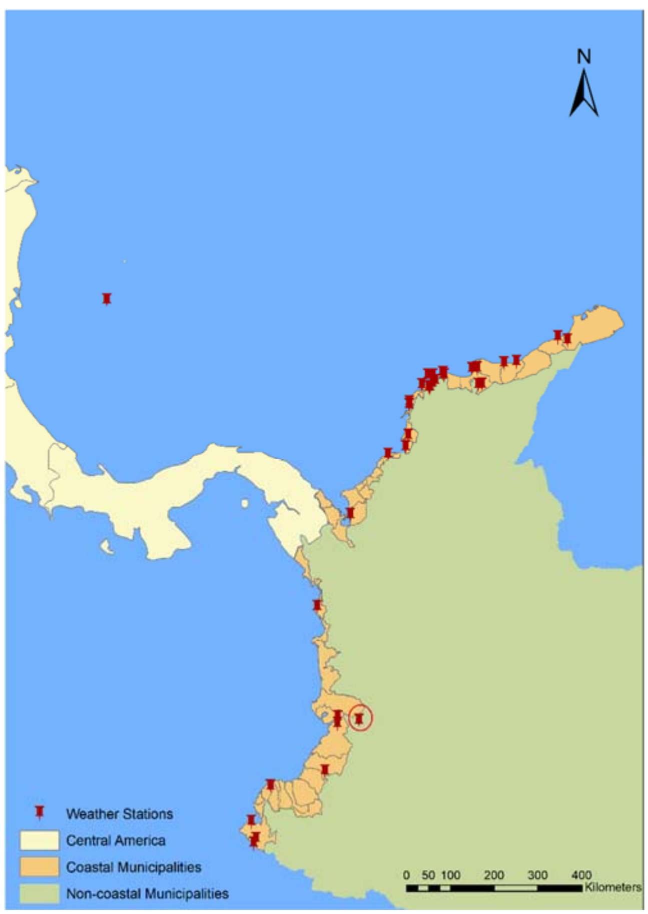
In this paper we have documented that organic mercury or methyl-mercury (i.e., mercury combined with carbon by microscopic organisms in water and soil) is present in fish and that its concentration increases along the food chain. We use a novel approach that relies on long time-series in sea surface temperature (SST) anomalies associated with atmospheric climate fluctuations to predict the methyl-mercury composition of fish catches consistent with the findings in marine biology that fish species differ in the sea temperatures in which they thrive. Using large administrative data sets providing high-school exit exam test scores and adult heights and census data on schooling attainment and occupation for individuals born in coastal communities in Colombia, for whom locally-caught fish is a diet staple, we are able to obtain the causal effects of exposure to both low-and high- mercury fish around birth on human capital outcomes later in life. As far as we know this is the first study that identifies the causal effect of early-age exposure to methyl-mercury on adult cognitive development.

Both small and big fishes have similar amounts of docosahexaenoic acid (DHA) which, according to medical research is good for the developing brain (i.e., around birth). However, big fishes have higher concentrations of organic mercury since methylmercury bioaccumulates along the food chain. In contrast to DHA, the medical literature suggests that organic mercury blocks the development of the brain in young children. Correspondingly, we find that when there is an abundance of low-mercury (small-) fish around the birth of a cohort induced by higher-than-average SSTs, children in this cohort will achieve higher test-scores and higher schooling attainment while having a higher probability of getting a white-collar job later in life. The DHA effect dominates the methyl-mercury effect: *Fish is brain food.* However, we also find that when the composition of coastal fish catches is dominated by high-mercury (big-) fish around the birth of a cohort, due to cooler ocean temperatures, children in this cohort will grow to have lower test-scores and lower schooling attainment while having a lower probability of getting a white-collar job. The methyl-mercury effect dominates the DHA effect: *Fish is brain poison.* We cannot detect any effects of exposure to these types of fish in later childhood, a finding that highlights the importance of the composition of foods when the brain is forming.

Fish will continue to be a major source of protein, especially among poor people all over the world. In the absence of the dissemination of information on the dangers of particular fish species for child development, a disproportionate fraction of the children of the poor will suffer cognitive impairments beyond those associated with lack of parental resources depending on global climate characteristics at birth. However, it would appear that climate change, which will increase average SSTs, will reduce the relative size of high-Hg fish populations, who prefer cooler sea temperatures, and thus elevate on average the cognitive development of children, especially among the poor.

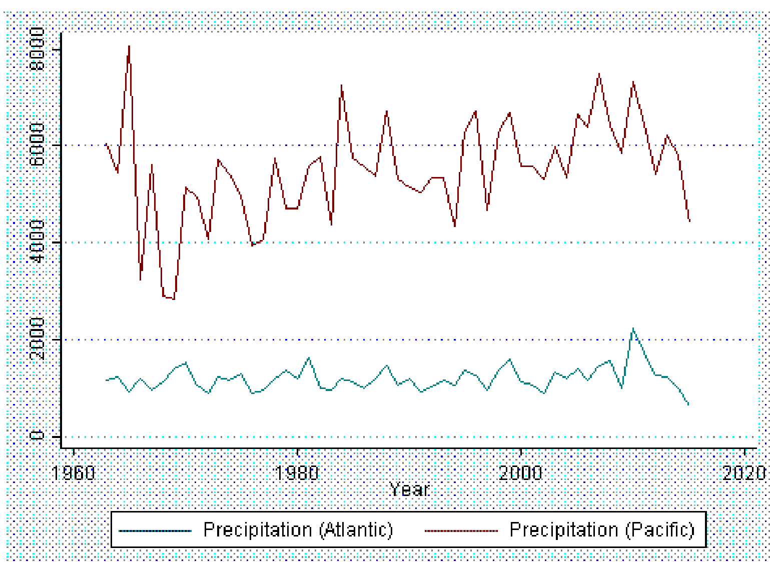
Appendix

Rainfall data come from IDEAM (Instituto de Hidrología Meteorología y Estudios Ambientales). IDEAM has several weather stations around the territory. The number of weather stations has increased over time, arriving later to the Pacific Coast, one of the most remote parts of Colombia. To obtain some precision, we restrict the time-series on rainfall to periods when we have at least five municipalities with rainfall data (active weather stations) out of the 16 municipalities in the Pacific. Table A1 shows the number of municipalities with at least one weather station by coast and year. Given the information provided in table A1, we use rainfall data starting in 1963. In that year, we also have rainfall information from weather stations in 16 of the 31 municipalities on the Atlantic.



The map shows the weather stations in 1963 and their intersection with our coastal municipalities. Notice that one station in the South-west of Colombia, the one inside a circle, is not inside a coastal municipality (but close). This mistake comes from the original database. In the original database, this station appears inside of Buenaventura, a coastal municipality. We keep that station as belonging to the municipality of Buenaventura even if it is 28 kilometers away from it. The weather station that appears to be located in the ocean is a weather station located in the Colombian Islands of San Andrés and Providencia, two of our coastal municipalities.

Stations turn on and off over time and we use information from all operating stations in a given coastal municipality each year. Thus, the number of stations is not constant over time. IDEAM reports rainfall data by month. We first aggregate over the months to have millimeters of precipitation per year. Yearly rainfall by coast is displayed in the following graph:



We use the annualized rainfall data to construct four-year moving averages that we append to the data on test scores, occupations and height so that they correspond to the first four years of life for each cohort post-conception, inclusive of the nine months in utero.

Figure 1. Percentage of Mothers Who Fed Fish to her Child Aged 9-24 Months, by Wealth Category and Location (Source: Colombia DHS 2010)

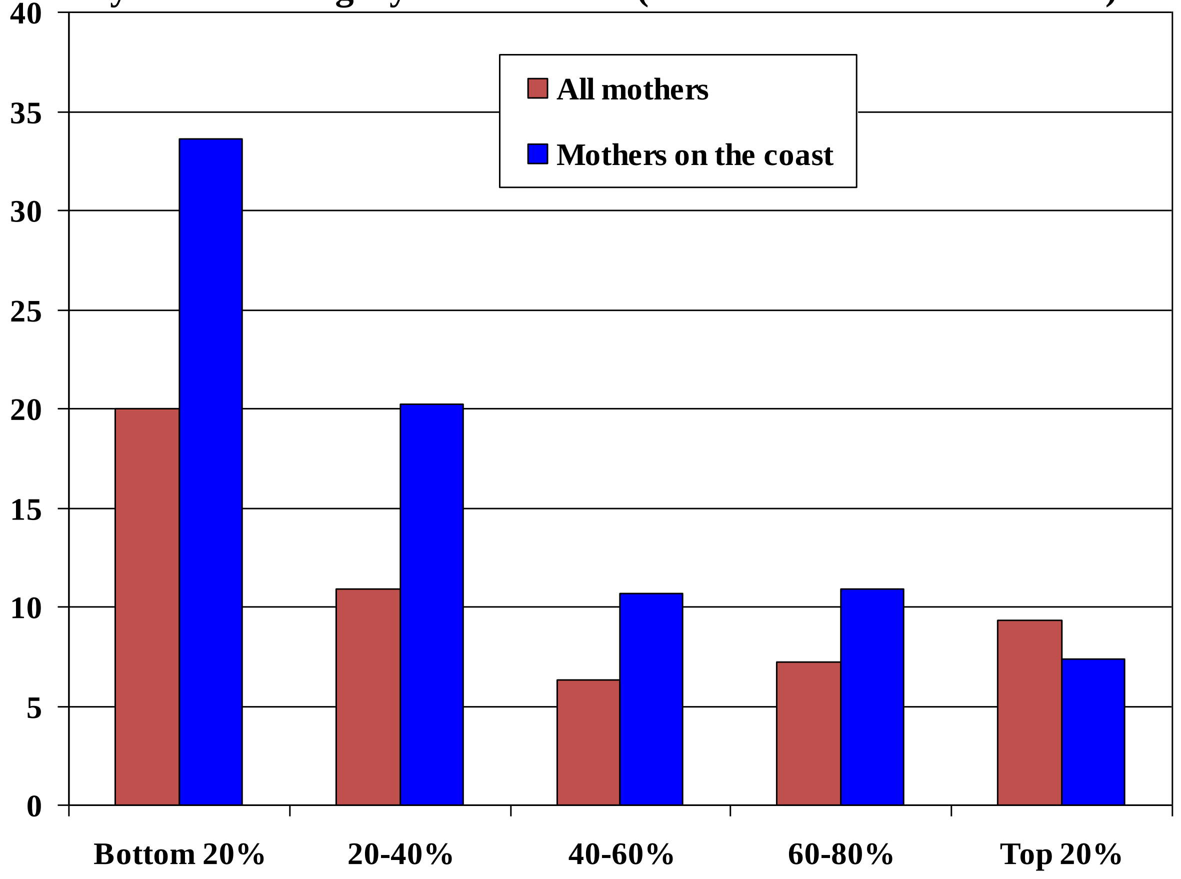


Figure 2. Percentage of Mothers Who Fed Meat to her Child Aged 9-24 Months, by Wealth Category and Location (Source: Colombia DHS 2010)

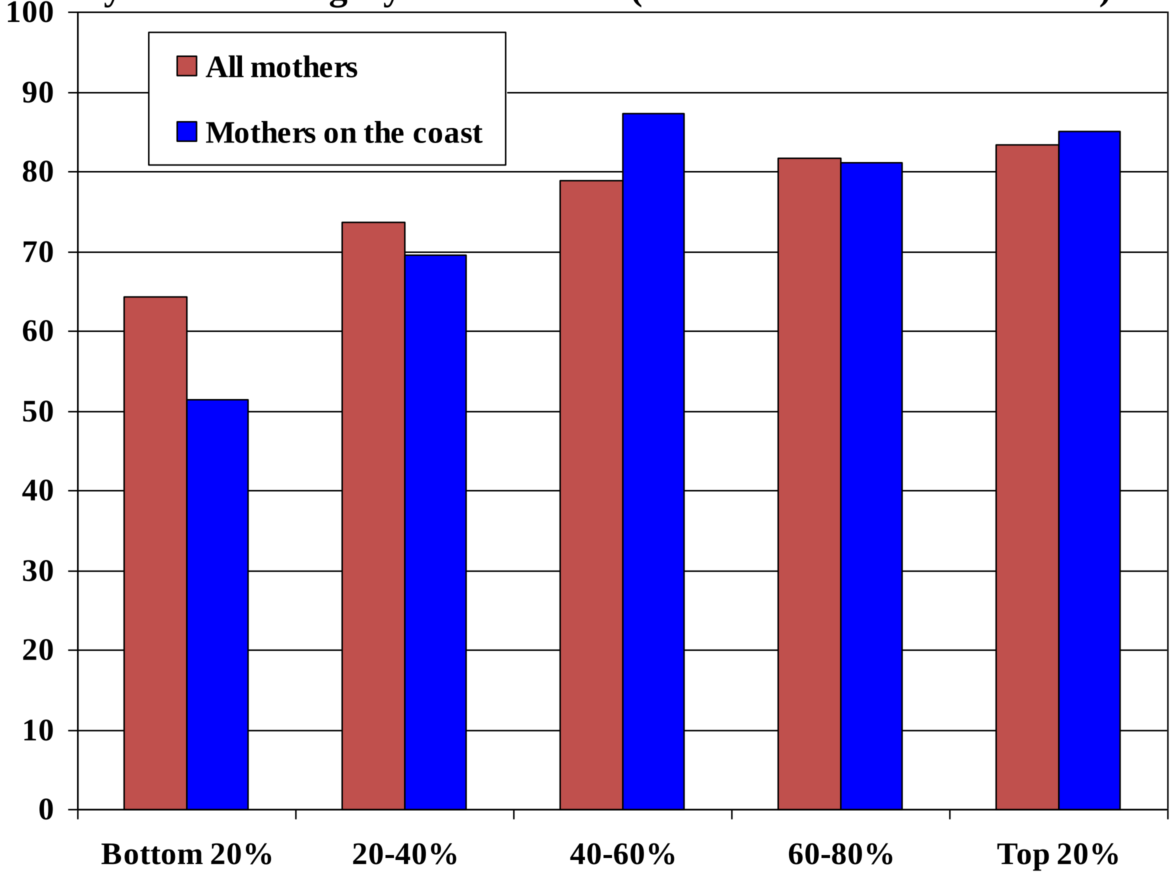


Figure 3. Mean Standardized PVT Scores of Children Aged 3-9, by Per-capita Income Category and Proximity to Coast (Source: Colombia ELCA 2013)

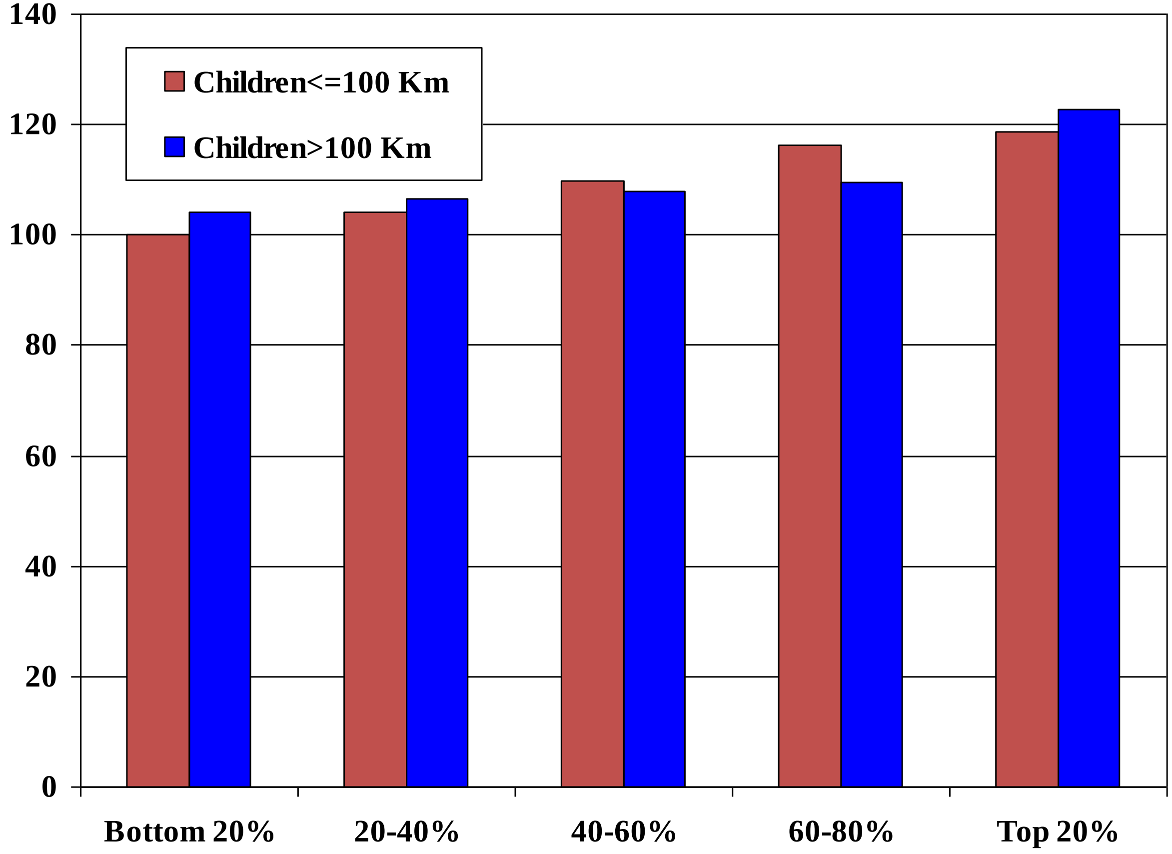


Figure 4. Equilibrium Price Setting: Rise in the Supply of K_L

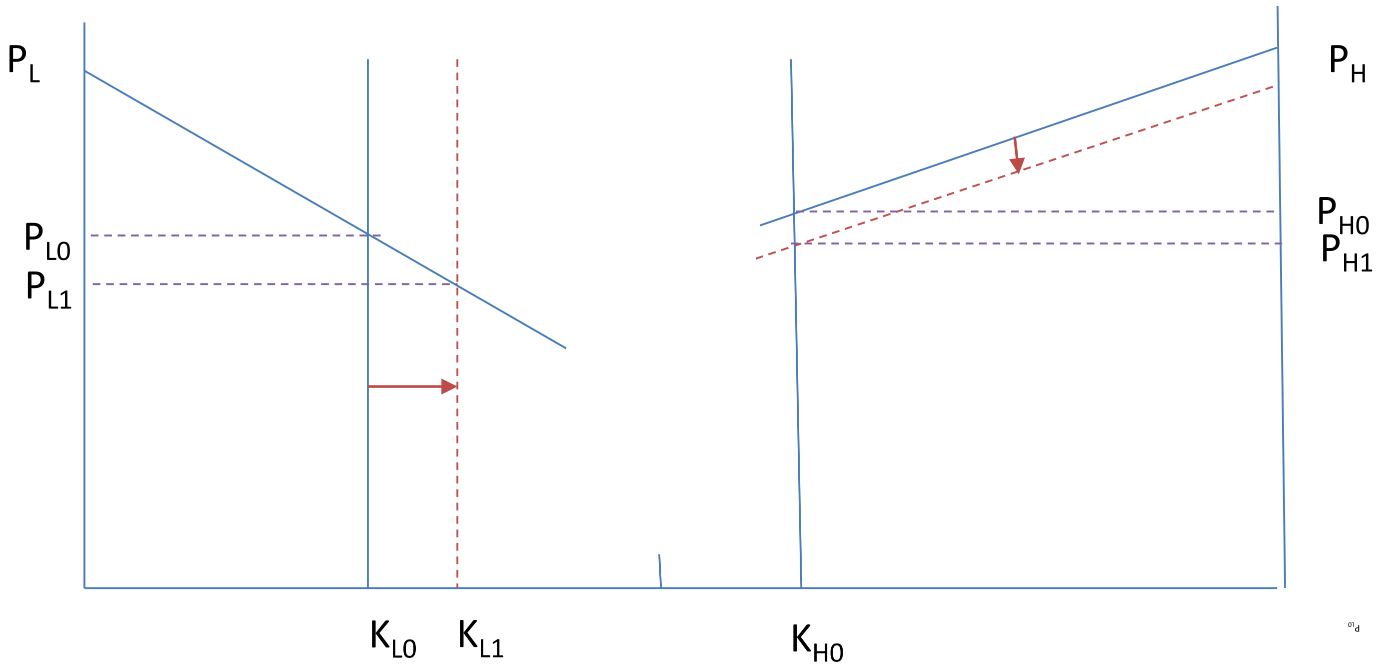


Figure 5. Equilibrium Price Setting: Rise in Income

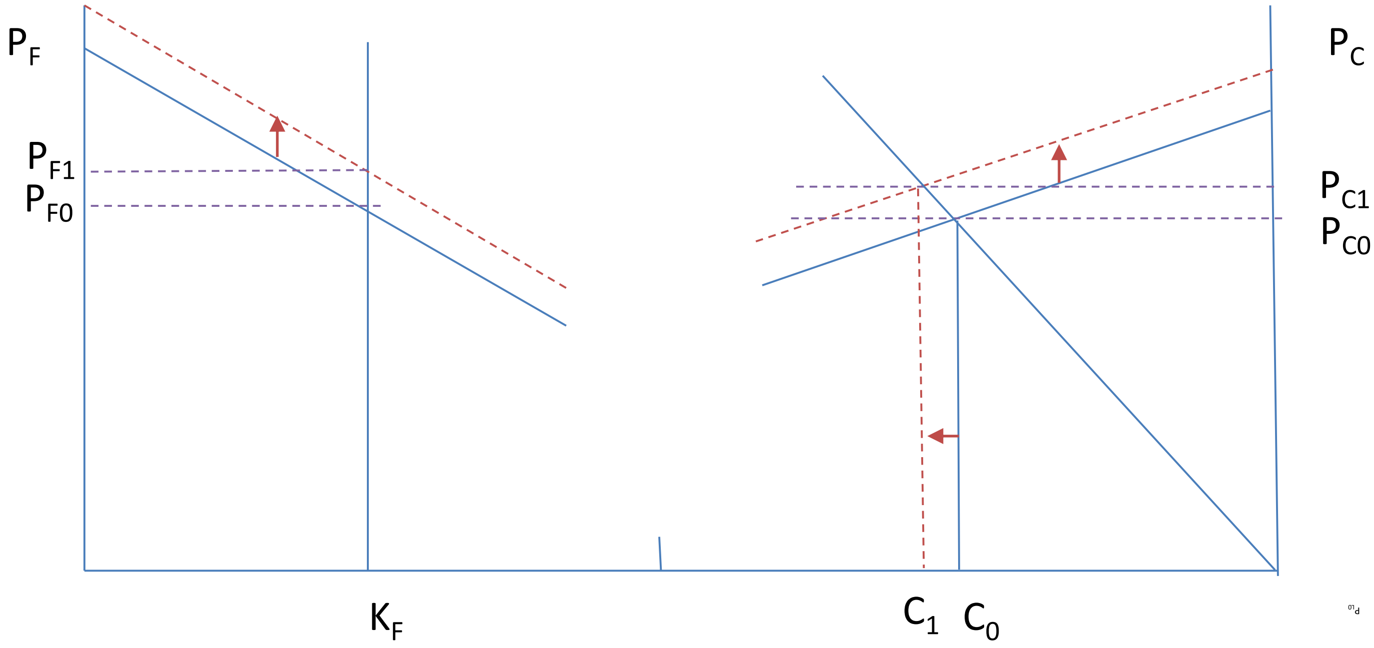


Figure 6: Total Tonnage ($x10^{-3}$) of Locally-Consumed Fish Catches by Coast and Year, Colombia Coasts 1950-2014, Three-Year Moving Average

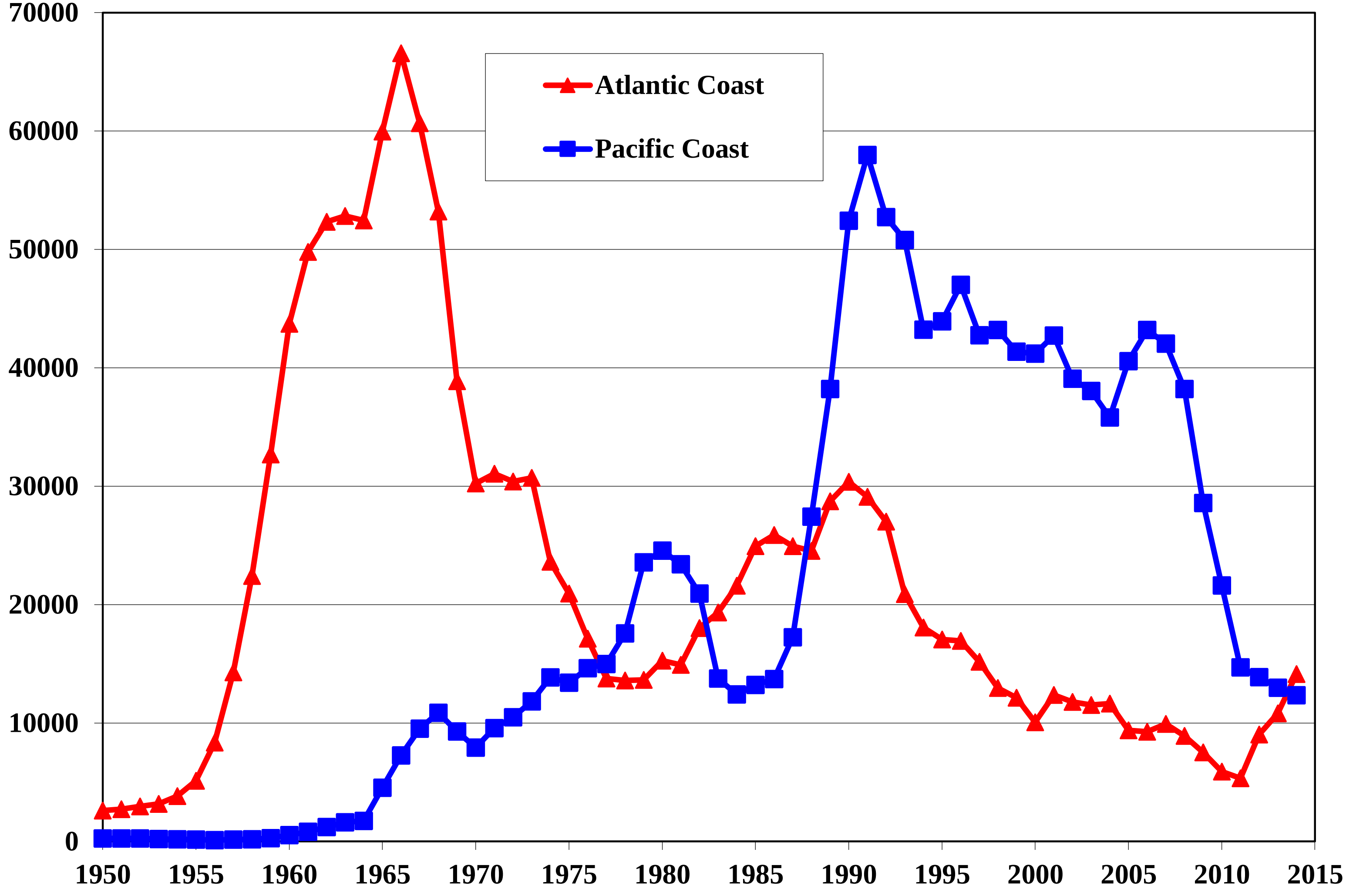


Figure 7. Average Hg and Omega-3 Concentrations Across 54 Species of Non-Industrial Fish, Colombia Pacific and Caribbean Coasts

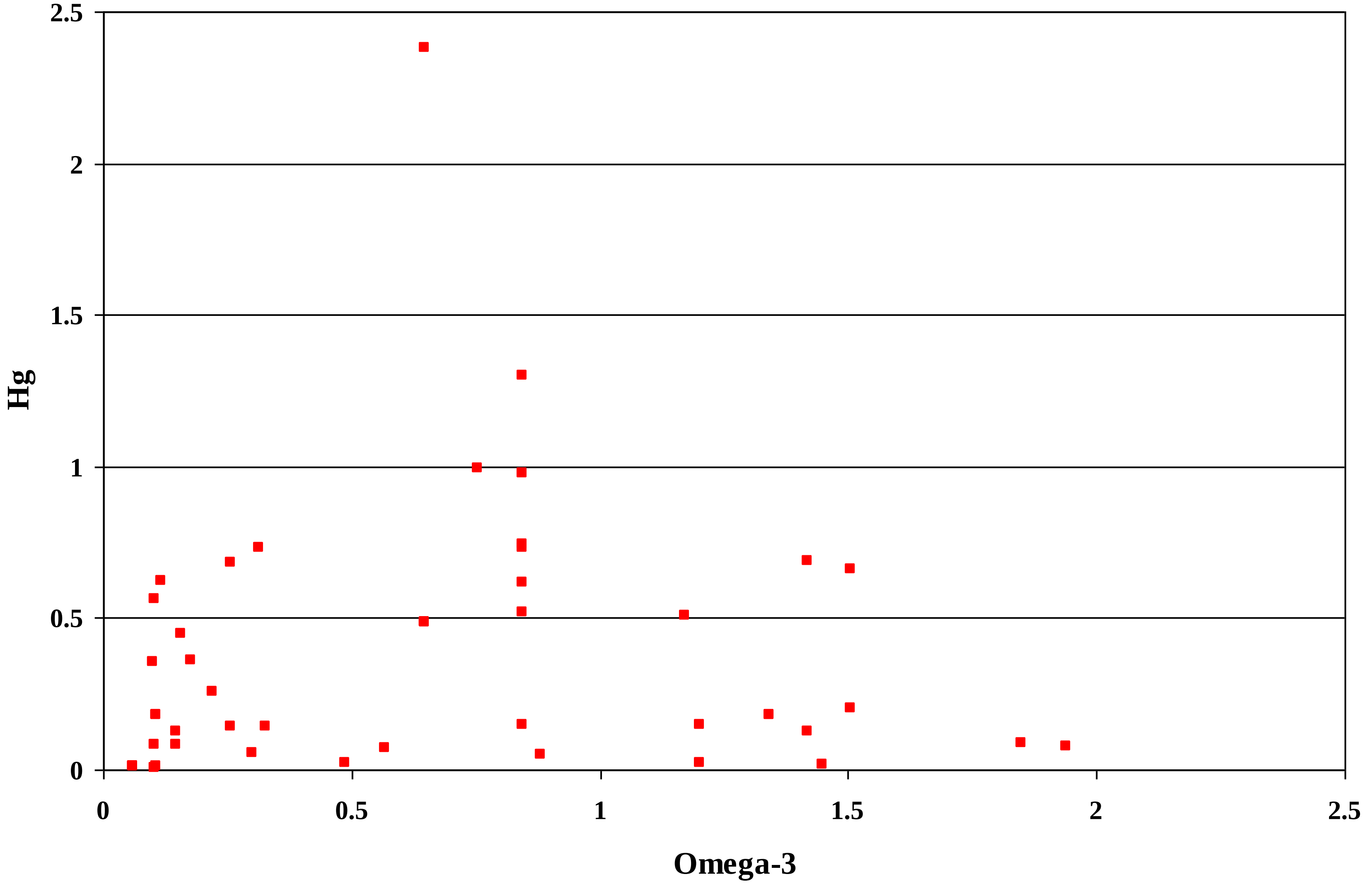


Figure 8: Total Tonnage ($x10^{-3}$) of Locally-Consumed Fish Catches by High and Low Mercury Levels, Coast and Year, Colombia Coasts 1950-2014, Three-Year Moving Average

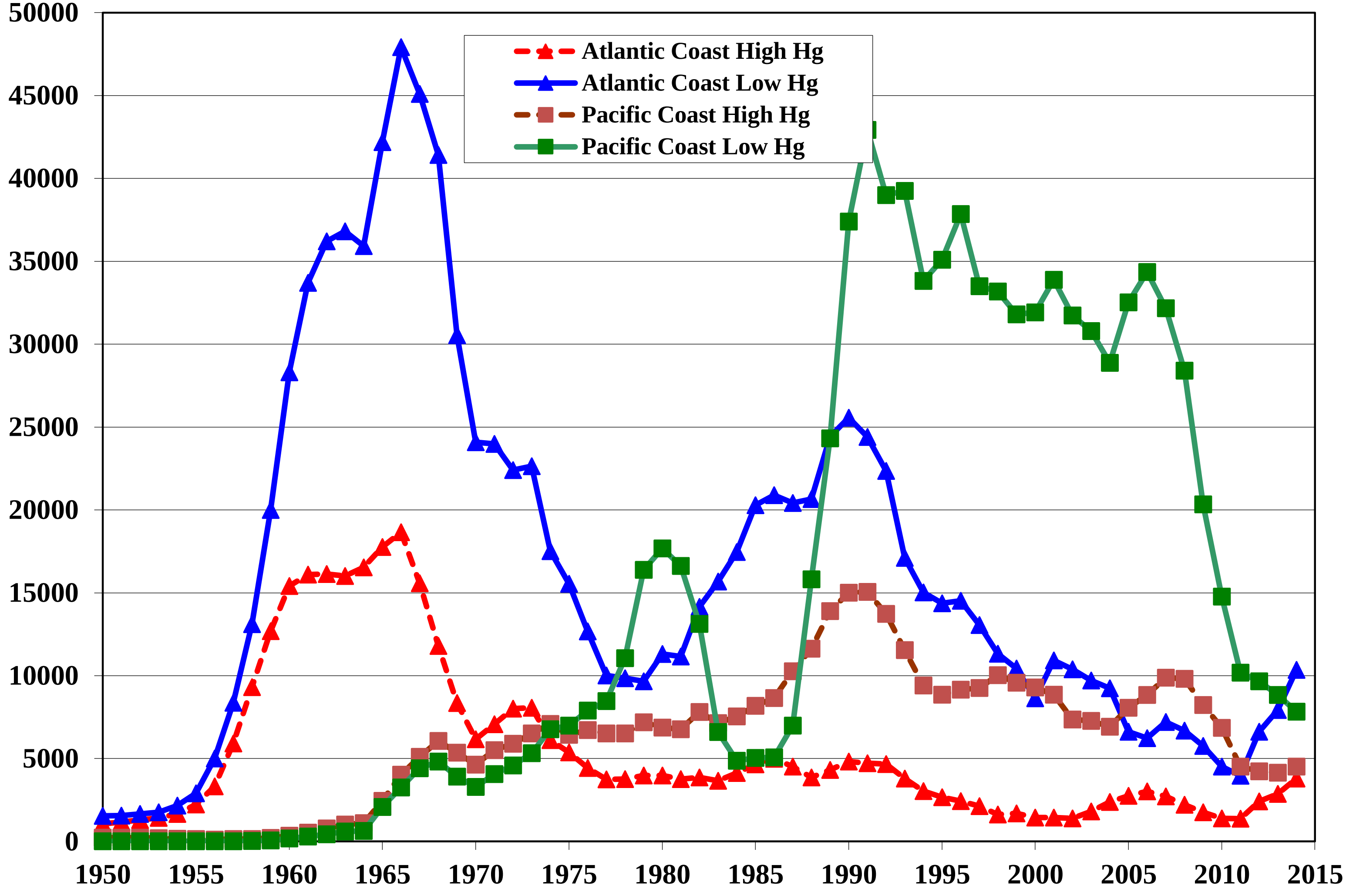


Figure 9: Mean Mercury Content of All Locally-Consumed Fishes Caught by Coast and Year, Colombia Coasts 1950-2014, Three-Year Moving Average

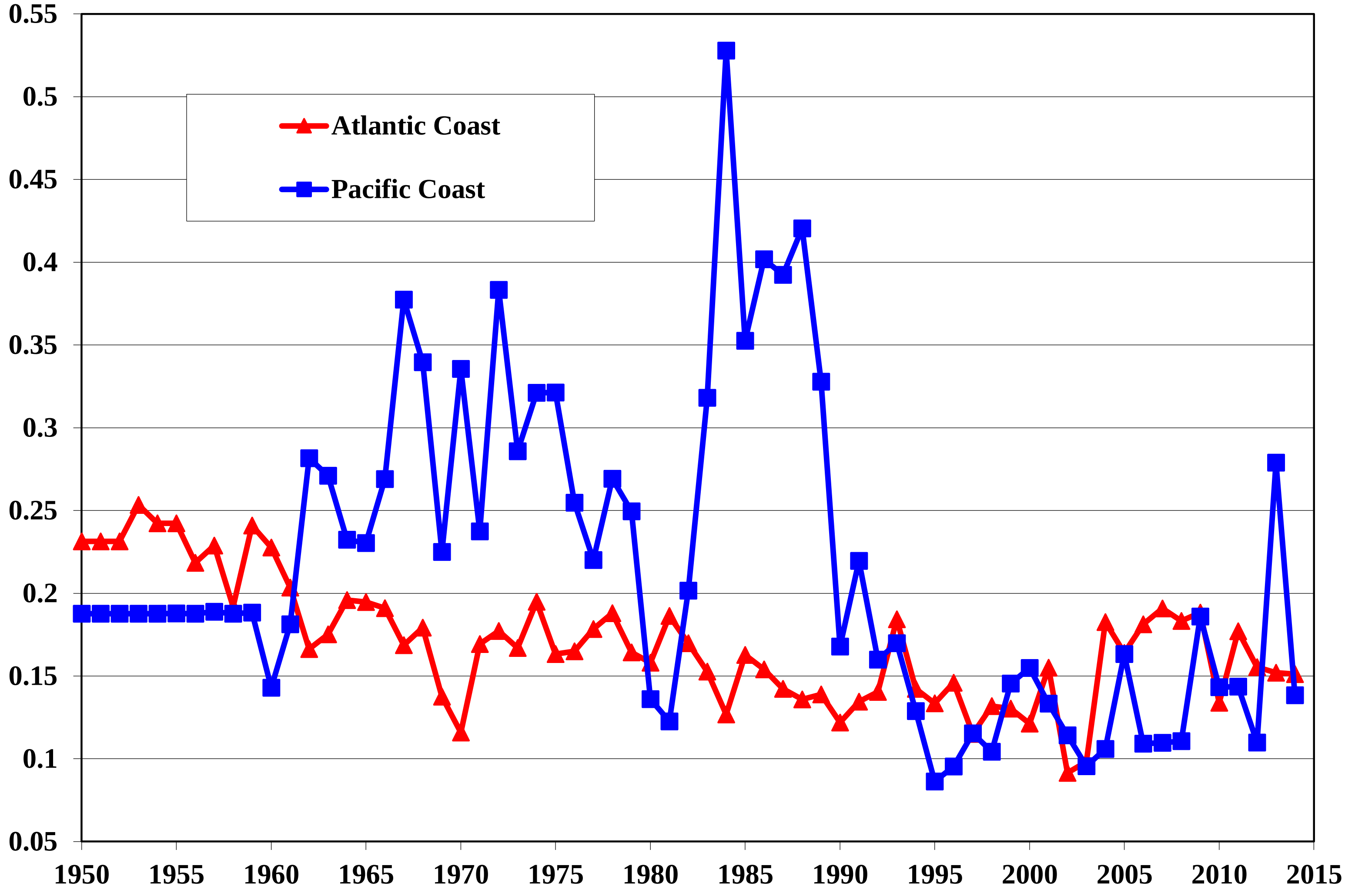


Figure 10. Number of Annual SST Anomalies by Coast and Year, Colombia Coasts 1950-2010, Four-Year Moving Average

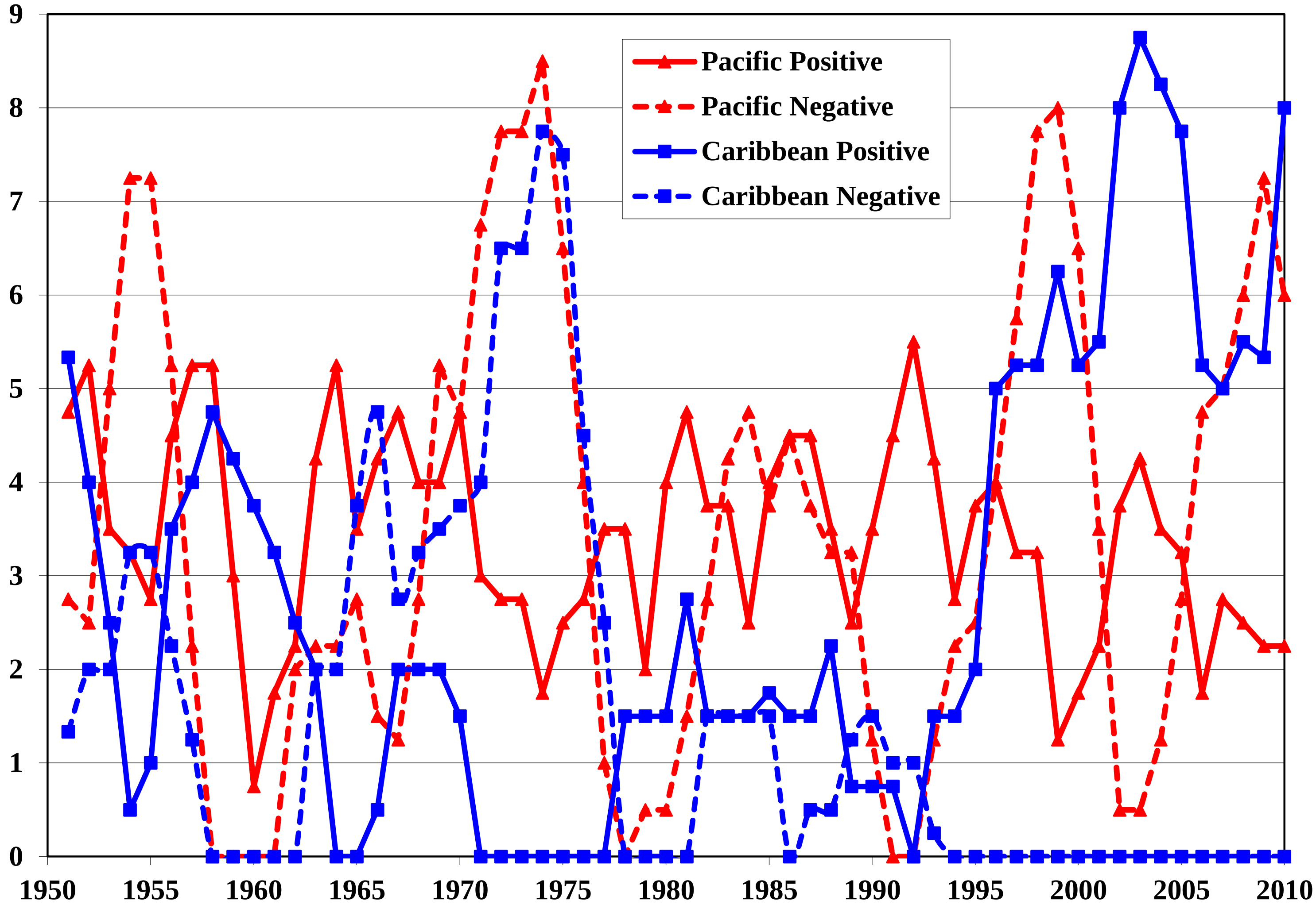


Figure 11: Mean Temperature Deviations (Centigrade) of SST Anomalies by Coast and Year, Colombia Coasts 1950-2010, Four-Year Moving Average

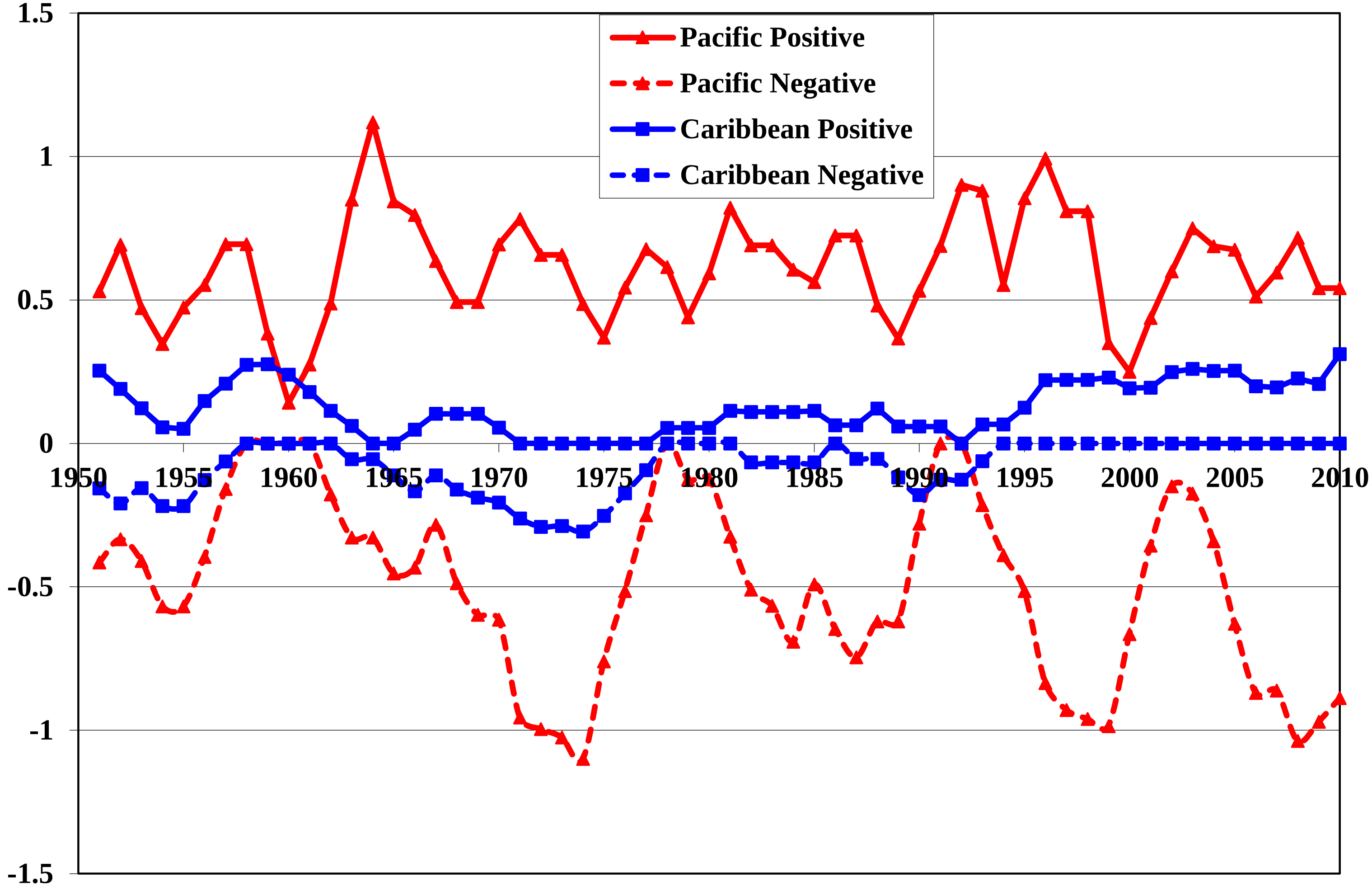


Figure 12: Price of Coastal Fish by Distance to the Coast (Kilometers)

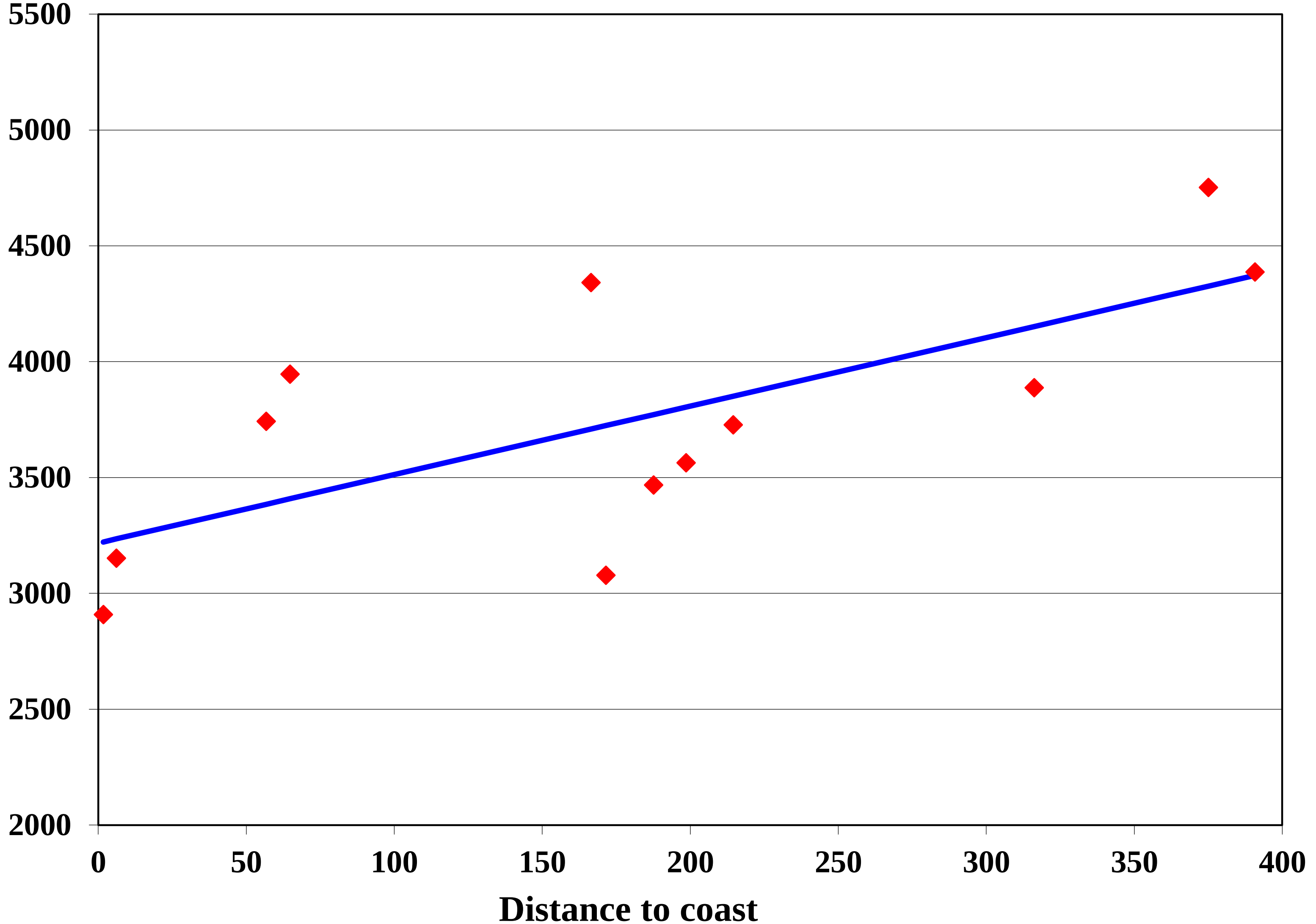


Figure 13: Price of Meat by Distance to the Coast (Kilometers)

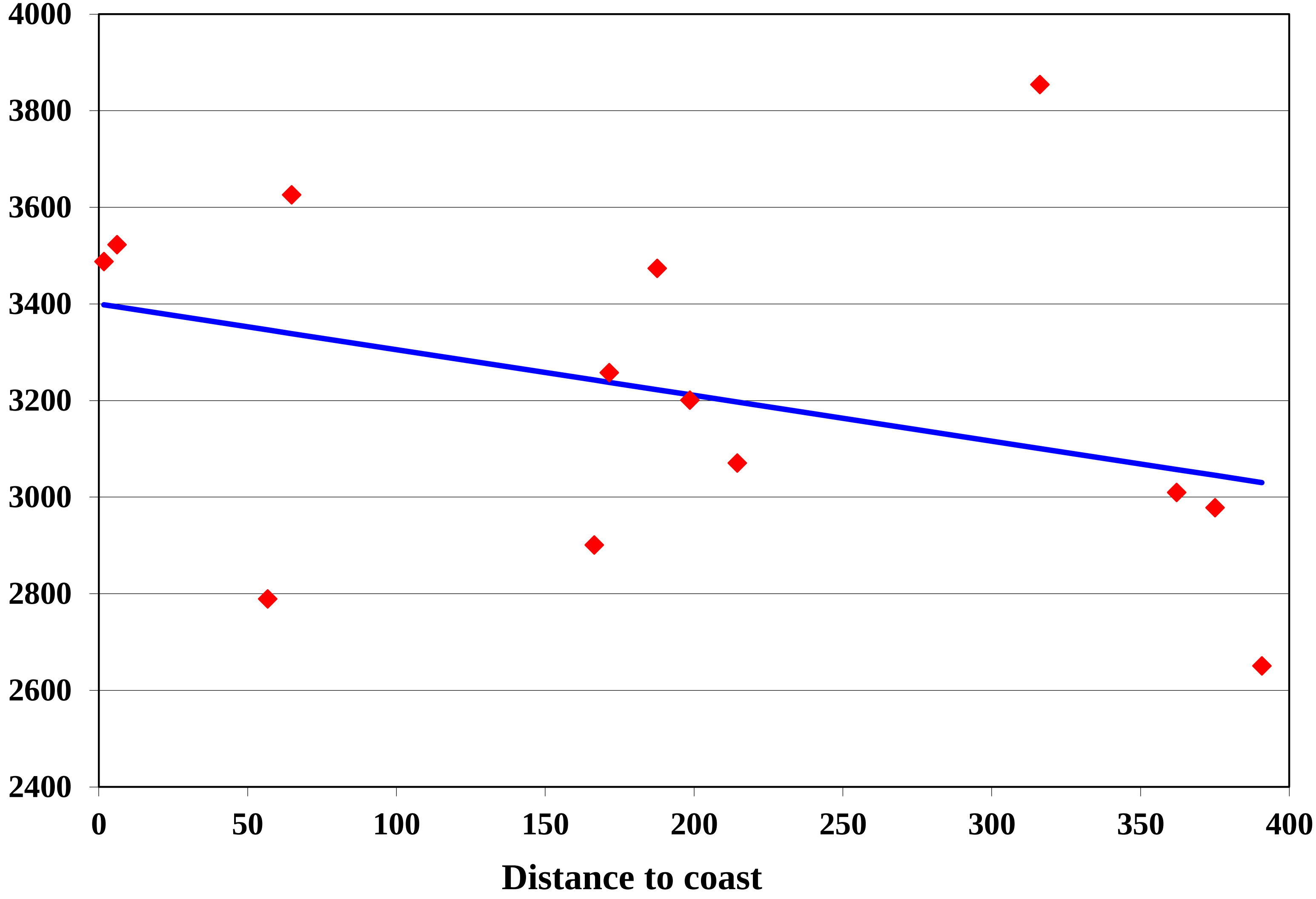


Figure 14. Log Deviations in the Log Real Price (Pesos) of Coastal Fish per 500 Grams and Log Deviations in the Coastal Fish Catch Size, for Four Coastal Cities, 1999-2013

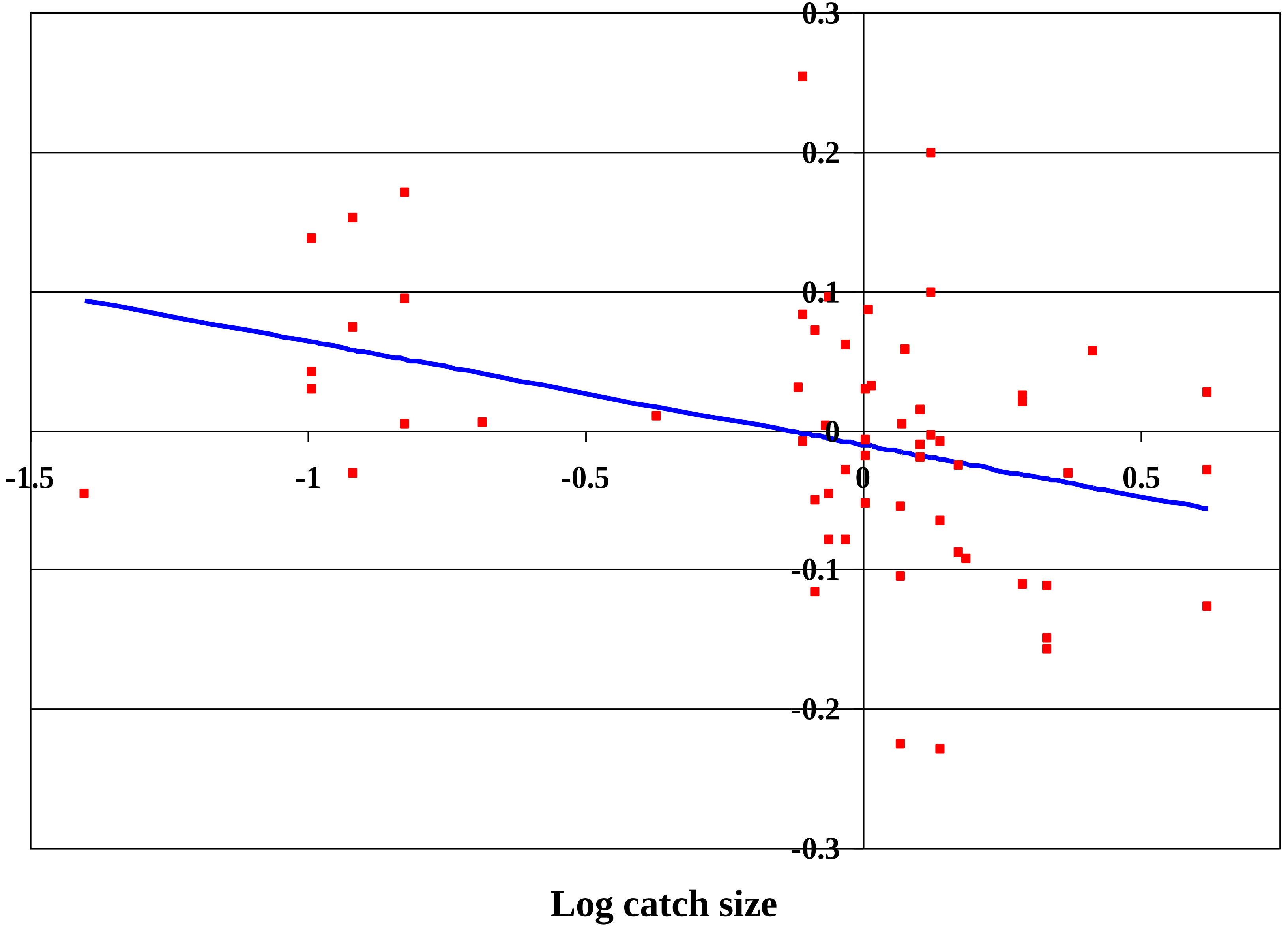


Table 1A: "Low" *Hg* Fish Species and Average Mercury Content (High Mercury if the latter is above 0.165). Surface Temperatures Spans (averages 2002-2011): Atlantic [22.9, 29.8], Pacific [18, 29.1]*

common name	Mercury (part per million)	minimum SST**	maximum SST**	Ocean (A: Atlantic; P:Pacific)
Pink conch	0.009	22.9	32.58	P
Sea snails	0.009	21.43	31.8	P
Venus clams	0.009	23.11	32.29	A, P
Mangrove cupped oyster	0.012	26.71	32.62	A
Pacific anchoveta	0.016	18.54	33.02	P
Sea catfishes, coblers	0.024	26.73	32.53	A
Squids	0.024	24.06	32.76	A, P
Threadfins	0.0279	21.22	33.26	P
Lebranche mullet	0.05	23.28	32.22	A
Mackerels, tunas, bonitos	0.05	19.22	31.89	A, P
Mullets, grey mullets	0.05	15.15	31.77	A, P
Wrasses, gropers, tuskfishes	0.05	25.44	32.26	P
Parrotfishes	0.053	22.9	32.32	P
Flatfishes	0.056	19.85	33.06	A, P
Jacks, pompanos	0.071	19.695	32	A, P
Herrings, sardines, menhadens	0.078	22.17	30.97	A, P
Panama hake	0.079	22.47	33.06	P
Mojarras, silverbellies	0.08	23.11	32.53	A, P
Blue spiny lobster	0.093	22.035	30.07	P
Caribbean spiny lobster	0.093	26.43	32.58	A
Perch-likes	0.121	22.04	32.22	A, P
Moray eels	0.128	26.32	32.58	P

Table 1B. "High" *Hg* Fish Species and Average Mercury Content (High Mercury if the latter is above 0.165). Surface Temperatures Spans (averages 2002-2011): Atlantic [22.9, 29.8], Pacific [18, 29.1]*

common name	Mercury (part per million)	minimum SST	maximum SST	Ocean (A: Atlantic; P:Pacific)
Lane snapper	0,166	22,16	32,24	A
Snappers	0,166	21,22	32,24	A, P
Southern red snapper	0,166	26,545	32,245	P
Basses, groupers, hinds	0,167	21,48	32,16	A, P
Broomtail grouper	0,167	17,265	33,06	P
Nassau grouper	0,167	26,645	32,58	A
Pacific sierra	0,18	18,58	31,48	P
Tarpon	0,2	20,845	32,16	A
Yellowtail snapper	0,22	22,84	32,26	A
Drums, croakers	0,2583	19.85	33,3	A, P
Pacific thread herring	0,3	21,78	31,37	P
Grunts, sweetlips, bonnetmouths	0,31	19,85	33,33	A, P
Amberjacks	0,444	24,27	31,73	A
Octopuses	0,445	26,61	32,49	A
Snooks	0,502	17,34	32,29	P
Lizardfishes, sauries	0,845	17,14	26,62	P
Sharks, rays, skates	0,979	14,45	31,52	A,P
Swordfish	0,995	23,39	32,31	A,P
Houndsharks	1,77	14,245	32,01	A,P
Smoothhounds	1,77	21,06	33,26	A,P
Average	**0,51**	**20,93**	**32,03**	
Span	**1,76**	**12,49**	**6,71**	

*Historic (2002-2011) average sea surface temperatures in the Atlantic and the Pacific come from Cherrington et al (2011). **Minimum and maximum sea surface temperatures are defined as the range of temperatures where the species can be found in Colombian maritime areas (source: Kaschner et al, 2016).

Table 2. Total Fish Catch and High and Low Mercury Fish Catches against Anomalies in Sea Surface Temperature (Total catch by year (1950 to 1998) and by Ocean (Atlantic and Pacific) in Tonnes from the Sea Around Us Website (www.seaaroundus.org) Based on Lindop et al. (2015) and Wielgus et al. (2010).)

	(1) Total Fish Catch	(2) Low Mercury Fish Catch	(3) High Mercury Fish Catch
Number of months in the year above the anomaly threshold	-5086.0 (3089.6)	-5122.8** (1960.6)	-669.4 (691.8)
Number of months in the year below the anomaly threshold	-8399.5*** (1866.2)	-3797.1*** (1415.3)	-2218.0*** (383.4)
Mean of positive temperature changes that were anomalous during the year	20876.8 (22265.9)	26033.9* (15424.3)	-3642.4 (4599.4)
Mean of negative temperature changes that were anomalous during the year	-67400.1*** (18424.4)	-24078.2* (13211.5)	-17130.3*** (4005.5)
Number of months in the year above the anomaly threshold X Atlantic Coast	-958.6 (3554.1)	2622.0 (2183.5)	-2406.5** (940.8)
Number of months in the year below the anomaly threshold X Atlantic Coast	15050.1*** (3505.1)	8254.6*** (2259.6)	4187.9*** (1027.0)
Mean of positive temperature changes that were anomalous during the year X Atlantic Coast	67337.5 (54732.4)	2504.8 (31803.4)	64262.0*** (18356.3)
Mean of negative temperature changes that were anomalous during the year X Atlantic Coast	208896.9*** (59958.0)	111523.9*** (35258.8)	59943.3*** (19691.7)
Observations	122	122	122
R-Squared	0.319	0.236	0.347
F-statistics	16.8	7.4	12.0
F-statistics *p*-value	(0.0)	(0.0)	(0.0)

Dependent variable: Fish Catch by Ocean (in Tonnes). The anomaly threshold in the Pacific is +/- 0.5 degrees Celsius. The anomaly threshold in the Atlantic is +/- 0.18 degrees Celsius. A month is anomalous if the three months moving average centered on that month exceeds the threshold. All variables are converted to yearly moving averages (1, 1, 2). Robust standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01

Table 3. Annual Rainfall (mm.) in both Coasts against Cold and Warm Episodes in Sea Surface Temperature in the Pacific (Rainfall from IDEAM and Deviations in Sea Surface Temperature from The National Weather Service www.nws.noaa.gov)

	(1) ONI Model	(2) Our Count Variables Instruments
Months in the Year within a Sequence of at Least 5 Consecutive Anomalous Cold Months	37.6** (16.6)	
Months in the Year within a Sequence of at Least 5 Consecutive Anomalous Warm Months	-42.3* (23.3)	
Anomalous Cold Months in the Year		28.2 (17.1)
Anomalous Warm Months in the Year		-54.1** (24.6)
Pacific Coast Indicator	4299.1*** (145.5)	4299.1*** (145.5)
Observations	106	106
R-Squared	0.897	0.897

Dependent variable: Rainfall in mm per year. Anomalous months are defined using deviations in Sea Surface Temperature: An anomalous cold (warm) month is a month 0.5 degrees below (above) the anomaly threshold. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 4. Log Real State GDP against Rainfall. State and Year Fixed Effects Estimates (DANE National Accounts: 1980-1998)

	(1)
Rainfall	0.00009*
	(0.00005)
	[0.09]
Observations	540
Number of States	33

Dependent variable: Log real state GDP by year (33 states). FE panel regressions. Standard errors clustered at the state level in parentheses. Wild bootstrapped p-value in brackets. p<0.10, ** p<0.05, *** p<0.01

Table 5. Any Fish Consumption by Children Aged 9 to 24 Months and Access to the Sea (2010 Colombia DHS)

	(1) All Municipalities	(2) Coastal Municipalities
Coastal Municipality	0.175***	
	(0.067)	
Fraction of Municipality Boundary that is Coastline		0.960**
		(0.363)
		[0.04]
Observations	7495	693
Number of Municipalities	221	15
Dependent variable mean	0.173	0.304
Dependent variable S.D.	0.379	0.461
State Fixed Effects	Y	N

Dependent variable: Any consumption of fish the day before the survey. OLS regressions for children 9 to 24 months old. Standard errors clustered at the municipality level in parentheses. Wild bootstrapped p-values in brackets. Individual-level controls : wealth quintiles indicators, age in months, male indicator, black indicator, native indicator, urban location, number of persons and children under 5 years old in the household, mother education and mother age. Municipality controls: Pacific coast dummy (only in column 2), average altitude in meters above sea level, index of aptitude of the soil for agriculture, maritime port, average yearly precipitation in the period 1980-2010 (millimeters), founding year of the municipality and volume of water that flows in rivers and lakes in 2000 (millions of cubic meters). * p<0.10, ** p<0.05, *** p<0.01

Table 6. Any Animal Protein Consumption by Children 9 to 24 Months and Access to the Sea within Coastal Municipalities (2010 Colombia DHS)

	(1)	(2)	(3)
	Meat	Egg	Animal Protein
Fraction of Municipality Boundary that is Coastline	-0.472*	0.867	0.075
	(0.225)	(0.512)	(0.135)
	[0.08]	[0.26]	[0.59]
Observations	694	691	694
Number of Municipalities	15	15	15
Dependent variable mean	0.700	0.346	0.912
Dependent variable S.D.	0.458	0.476	0.283

Dependent variable: Any consumption of the corresponding protein aggregate the day before the survey. Animal protein is consumption of either red meat, white meat, packed meat or eggs. Meat excludes the latter. OLS regressions for children 9 to 24 months old. Standard errors clustered at the municipality level in parentheses. Wild bootstrapped p-values in brackets. The parameter estimates (and standard errors) of the individual categories of Meat against the fraction of the municipality boundary that is coastline and the corresponding controls are: **red meat: -0.330 (0.245) [0.3]; white meat: -0.800** (0.289) [0.03]; packed meat: 0.476** (0.193) [0.07]**. Individual-level controls: Wealth quintiles indicators, age in months, male indicator, black indicator, native indicator, urban location, number of persons and children under 5 years old in the household, mother education and mother age. Municipality controls: Pacific coast indicator, average altitude in meters above sea level, index of aptitude of the soil for agriculture, maritime port indicator, average yearly precipitation in the period 1980-2010 (millimeters), founding year of the municipality and volume of water that flows in rivers and lakes in 2000 (millions of cubic meters).* p<0.10, ** p<0.05, *** p<0.01

Table 7. Log Real Price of Fish in Four Cities close to the Sea (Barranquilla, Cartagena & Monteria in the Atlantic; Cali in the Pacific) against the Log of Total Fish Catch in each Coast. City Fixed Effects Estimates (DANE Price Indices 1999-2013)

	(1) FE	(2) IV-FE
Log Fish Catch (in Tonnes)	-0.0530*	-0.1129**
	(0.0275)	(0.0502)
Log Rain in each Coast	0.0971	0.0329
	(0.0700)	(0.0796)
Observations	60	60
Number of Municipalities	4	4
Kleibergen-Paap rk LM statistic		15.583
Kleibergen-Paap rk LM statistic *p*-value		0.029
Hansen J statistic		6.514
Hansen J statistic *p*-value		0.368

Dependent variable: Log real price of fish. The four cities are also municipalities. IV instruments are anomalies in the temperature of the sea surface: Number of three months moving averages centered around each month in the year above (below) the anomaly threshold: +0.5 (-0.5) Celsius in the Pacific and +0.18 (-0.18) Celsius in the Caribbean, mean of the positive (negative) temperature changes that were anomalous during the corresponding three months moving averages that year. Since the threshold varies by ocean, we interact each of these variables with an indicator for Atlantic coast. An additional instrument is an indicator that takes the value of one if no information on sea surface temperature is available. Thus we use nine instruments. Robust standard errors in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 8. Standardized Verbal Test Scores against Total Fish Catch and against High and Low Mercury Fish Catches Around Birth. Individuals Born and Potentially Staying in Coastal Municipalities. Municipality and year fixed effects estimates (Saber 11 High School Exit Exams for Individuals Born in 1963-1998)

	(1) FE	(2) IV-FE	(3) IV-FE	(4) FE	(5) IV-FE	(6) IV-FE
Fish Catch around Birth (Thousand Tonnes) X	-0.0029***	-0.0011	-0.00002			
Fraction of Municipality Boundary that is Coastline	(0.0010)	(0.0029)	(0.0024)			
High Mercury Fish Catch around Birth (Thousand Tonnes) X				-0.0390***	-0.0532***	-0.0521***
Fraction of Municipality Boundary that is Coastline				(0.0071)	(0.0129)	(0.0114)
Low Mercury Fish Catch around Birth (Thousand Tonnes) X				0.0074***	0.0115***	0.0129***
Fraction of Municipality Boundary that is Coastline				(0.0023)	(0.0028)	(0.0026)
Schools per Municipality (Divided by 1000)	0.1446	0.1674	0.1551	0.1629	0.1721	0.1622
	(0.2790)	(0.2765)	(0.2737)	(0.2810)	(0.2773)	(0.2747)
Average Rainfall Around Birth (Divided by 1000)			-0.0651			-0.0734*
			(0.0411)			(0.0415)
Observations	1184817	1184817	1184817	1184817	1184817	1184817
Number of Municipalities	47	47	47	47	47	47
Kleibergen-Paap rk LM statistic		17.872	18.669		20.177	21.179
Kleibergen-Paap rk LM statistic *p*-value		0.022	0.017		0.005	0.004
Hansen J statistic		12.087	11.425		8.337	5.847
Hansen J statistic *p*-value		0.098	0.121		0.214	0.441

Dependent variable: Verbal test scores in high-school exit exams standardized by year. Independent variables measured around birth are four year moving averages (1,1,2): the year before birth and the three first years of life. FE and IV-FE stacked cross-sections regressions of individuals circa 17 years old. IV instruments are anomalies in the temperature of the sea surface: Number of three months moving averages centered around each month in the year above (below) the anomaly threshold: +0.5 (-0.5) Celsius in the Pacific and +0.18 (-0.18) Celsius in the Caribbean, mean of the positive (negative) temperature changes that were anomalous during the corresponding three months moving averages that year. Since the threshold varies by ocean, we interact each of these variables with an indicator for Atlantic coast. All variables are also interacted with the fraction of the municipality border that is coastline. Thus we have 8 instruments. Standard errors clustered at the municipality level in parentheses. * p<0.10, ** p<0.05, *** p<0.01

Table 9. Standardized Math Test Scores against Total Fish Catch and against High and Low Mercury Fish Catches Around Birth. Individuals Born and Potentially Staying in Coastal Municipalities. Municipality and year fixed effects estimates (Saber 11 High School Exit Exams for Individuals Born in 1963-1998)

	(1) FE	(2) IV-FE	(3) IV-FE	(4) FE	(5) IV-FE	(6) IV-FE
Fish Catch around Birth (Thousand Tonnes) X	-0.0078***	-0.0045	-0.0040			
Fraction of Municipality Boundary that is Coastline	(0.0024)	(0.0032)	(0.0028)			
High Mercury Fish Catch around Birth (Thousand Tonnes) X				-0.0267**	-0.0399**	-0.0395**
Fraction of Municipality Boundary that is Coastline				(0.0119)	(0.0170)	(0.0163)
Low Mercury Fish Catch around Birth (Thousand Tonnes) X				-0.0025	0.0039	0.0043
Fraction of Municipality Boundary that is Coastline				(0.0022)	(0.0029)	(0.0028)
Schools per Municipality (Divided by 1000)	0.6004***	0.6415***	0.6340***	0.6007***	0.6386***	0.6316***
	(0.2201)	(0.2201)	(0.2197)	(0.2200)	(0.2197)	(0.2193)
Average Rainfall Around Birth (Divided by 1000)			-0.0363			-0.0344
			(0.0427)			(0.0450)
Observations	1184816	1184816	1184816	1184816	1184816	1184816
Number of Municipalities	47	47	47	47	47	47
Kleibergen-Paap rk LM statistic		17.872	18.669		20.176	21.179
Kleibergen-Paap rk LM statistic *p*-value		0.022	0.017		0.005	0.004
Hansen J statistic		9.282	10.107		7.467	8.574
Hansen J statistic *p*-value		0.233	0.183		0.280	0.199

Dependent variable: Math test scores in high-school exit exams standardized by year. Independent variables measured around birth are four year moving averages (1,1,2): the year before birth and the three first years of life. FE and IV-FE stacked cross-sections regressions of individuals circa 17 years old. IV instruments are anomalies in the temperature of the sea surface: Number of three months moving averages centered around each month in the year above (below) the anomaly threshold: +0.5 (-0.5) Celsius in the Pacific and +0.18 (-0.18) Celsius in the Caribbean, mean of the positive (negative) temperature changes that were anomalous during the corresponding three months moving averages that year. Since the threshold varies by ocean, we interact each of these variables with an indicator for Atlantic coast. All variables are also interacted with the fraction of the municipality border that is coastline. Thus we have 8 instruments. Standard errors clustered at the municipality level in parentheses. * p<0.10, ** p<0.05, *** p<0.01

Table 10. Height (cm.) of Citizens circa 18 Years Old Born in 1963-1997 against Total Fish Catch and against High and Low Mercury Fish Catches around Birth. Individuals Born and Registering as Citizens in the Same Coastal Municipality. Municipality and year fixed effects estimates (Identification Cards from the National Civil Registry)

	(1) FE	(2) IV-FE	(3) IV-FE	(4) FE	(5) IV-FE	(6) IV-FE
Fish Catch around Birth (Thousand Tonnes) X	0.0437***	0.0596**	0.0502*			
Fraction of Municipality Boundary that is Coastline	(0.0131)	(0.0257)	(0.0259)			
High Mercury Fish Catch around Birth (Thousand Tonnes) X				-0.0136	0.0285	0.0869
Fraction of Municipality Boundary that is Coastline				(0.0695)	(0.0732)	(0.0888)
Low Mercury Fish Catch around Birth (Thousand Tonnes) X				0.0679**	0.0677**	0.0422
Fraction of Municipality Boundary that is Coastline				(0.0268)	(0.0283)	(0.0344)
Male	11.5801***	11.5804***	11.5807***	11.5804***	11.5805***	11.5808***
	(0.2217)	(0.2217)	(0.2216)	(0.2218)	(0.2217)	(0.2216)
Average Rainfall Around Birth (Divided by 1000)			0.0005***			0.0005**
			(0.0002)			(0.0002)
Observations	1842224	1842224	1842224	1842224	1842224	1842224
Number of Municipalities	47	47	47	47	47	47
Kleibergen-Paap rk LM statistic		13.737	11.819		14.800	15.160
Kleibergen-Paap rk LM statistic *p*-value		0.089	0.159		0.039	0.034
Hansen J statistic		5.548	7.355		4.742	5.356
Hansen J statistic *p*-value		0.593	0.393		0.577	0.499

Dependent variable: Height of individuals reported in their citizen identification card. The height is measured by officers at the municipality Civil Registry. Individual can ask for their identification card after turning 18 years old. Independent variables measured around birth are four-year moving averages (1, 1,2): the year before birth and the three first years of life. FE and IV-FE stacked cross-sections regressions of individuals 18 years of age (or the age when they decide to register) and Born Between 1951 and 1997 . IV instruments are anomalies in the temperature of the sea surface: Number of three months moving averages centered around each month in the year above (below) the anomaly threshold: +0.5 (-0.5) Celsius in the Pacific and +0.18 (-0.18) Celsius in the Caribbean, mean of the positive (negative) temperature changes that were anomalous during the corresponding three months moving averages that year. Since the threshold varies by ocean, we interact each of these variables with an indicator for Atlantic coast. All variables are also interacted with the fraction of the municipality border that is coastline. Thus we have 8 instruments. Standard errors clustered at the municipality level in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 11. Standardized Verbal Test Scores against Total Fish Catch and against High and Low Mercury Fish catches at Different Ages. Individuals Born and Potentially Staying in Coastal Municipalities. Municipality and year fixed effects estimates (Saber 11 High School Exit Exams 1963-1998)

	(1) FE	(2) IV-FE	(3) IV-FE	(4) FE	(5) IV-FE	(6) IV-FE
Fish Catch around Birth X Fraction of Municipality Boundary that is Coastline	-0.0019** (0.0008)	-0.0019 (0.0015)	0.0022 (0.0019)			
High Mercury Fish Catch around Birth X Fraction of Municipality Boundary that is Coastline				-0.0349*** (0.0056)	-0.0425*** (0.0074)	-0.0349*** (0.0096)
Low Mercury Fish Catch around Birth X Fraction of Municipality Boundary that is Coastline				0.0090*** (0.0021)	0.0098*** (0.0029)	0.0147*** (0.0036)
Fish Catch during the Years from 7 to 10 X Fraction of Municipality Boundary that is Coastline	-0.0060** (0.0029)	-0.0015 (0.0052)	-0.0017 (0.0062)			
High Mercury Fish Catch during the Years from 7 to 10 X Fraction of Municipality Boundary that is Coastline				0.0036 (0.0092)	0.0005 (0.0090)	0.0073 (0.0094)
Low Mercury Fish Catch during the Years from 7 to 10 X Fraction of Municipality Boundary that is Coastline				-0.0088** (0.0036)	-0.0017 (0.0042)	-0.0060 (0.0091)
Average Rainfall around Birth (Divided by 1000)			-0.0199 (0.0544)			-0.0055 (0.0762)
Average Rainfall during the Years from 7 to 10 (Divided by 1000)			-0.1475** (0.0641)			-0.1770*** (0.0640)
Observations	1184817	1184817	1184817	1184817	1184817	1184817
Number of Municipalities	47	47	47	47	47	47
Kleibergen-Paap rk LM statistic		25.302	35.188		14.583	24.925
Kleibergen-Paap rk LM statistic *p*-value		0.046	0.002		0.334	0.024
Hansen J statistic		17.957	18.305		17.759	14.228
Hansen J statistic *p*-value		0.209	0.193		0.123	0.286

Dependent variable: Verbal test scores in high-school exit exams standardized by year. FE and IV-FE stacked cross-sections regressions of individuals circa 17 years old. Independent variables measured around birth are four year moving averages (1,1,2): the year before birth and the three first years of life. Independent variables measured during the years from 7 to 10 are these four year averages. IV instruments: See Table @. In addition, we use the same set of instruments for the relevant years when the cohorts are aged 7-10. Thus, we have 16 instruments. Controls not shown: Schools per Municipality (Divided by 1000). Standard errors clustered at the municipality level in parentheses. * p<0.10, ** p<0.05, *** p<0.01

Table 12. Standardized Math Test Scores against Total Fish Catch and against High and Low Mercury Fish catches at different ages. Individuals Born and Potentially Staying in Coastal Municipalities. Municipality and year fixed effects estimates (Saber 11 High School Exit 1963-1998)

	(1) FE	(2) IV-FE	(3) IV-FE	(4) FE	(5) IV-FE	(6) IV-FE
Fish Catch around Birth X	-0.0061***	-0.0038*	0.0020			
Fraction of Municipality Boundary that is Coastline	(0.0018)	(0.0020)	(0.0024)			
High Mercury Fish Catch around Birth X				-0.0208**	-0.0219***	-0.0085
Fraction of Municipality Boundary that is Coastline				(0.0090)	(0.0073)	(0.0123)
Low Mercury Fish Catch around Birth X				-0.0001	0.0020	0.0075
Fraction of Municipality Boundary that is Coastline				(0.0022)	(0.0029)	(0.0049)
Fish Catch during the Years from 7 to 10 X	-0.0101***	-0.0067	-0.0079			
Fraction of Municipality Boundary that is Coastline	(0.0031)	(0.0066)	(0.0081)			
High Mercury Fish Catch during the Years from 7 to 10 X				-0.0017	-0.0169	0.0147
Fraction of Municipality Boundary that is Coastline				(0.0102)	(0.0138)	(0.0121)
Low Mercury Fish Catch during the Years from 7 to 10 X				-0.0116***	-0.0020	-0.0186
Fraction of Municipality Boundary that is Coastline				(0.0038)	(0.0055)	(0.0122)
Average Rainfall around Birth (Divided by 1000)			0.0638			0.1258
			(0.0666)			(0.1043)
Average Rainfall during the Years from 7 to 10 (Divided by			-0.2505***			-0.2704***
1000)			(0.0719)			(0.0659)
Observations	1184816	1184816	1184816	1184816	1184816	1184816
Number of Municipalities	47	47	47	47	47	47
Kleibergen-Paap rk LM statistic		25.302	35.188		14.583	24.925
Kleibergen-Paap rk LM statistic *p*-value		0.046	0.002		0.334	0.024
Hansen J statistic		16.696	17.620		15.259	14.685
Hansen J statistic *p*-value		0.273	0.225		0.228	0.259

Dependent variable: Math test scores in high-school exit exams standardized by year. FE and IV-FE stacked cross-sections regressions of individuals circa 17 years old. Independent variables measured around birth are four-year moving averages (1, 1, 2): the year before birth and the three first years of life. Independent variables measured during the years from 7 to 10 are these four year averages. IV instruments: See Table @. In addition, we use the same set of instruments for the relevant years when the cohorts are aged 7-10. Thus, we have 16 instruments. Controls not shown: Schools per Municipality (Divided by 1000). Standard errors clustered at the municipality level in parentheses. * p<0.10, ** p<0.05, *** p<0.01

Table 13: Colombian Real Price of Rice against International Price of Rice and against Colombian Rice Production: 1996-2019 (Source of variables: FEDEARROZ for Colombian data and Federal Reserve Bank of St. Louis for international data)

	(1)	2)
Log of International Rice Price	0.2111***	0.2095***
	(0.0583)	(0.0593)
Log of Colombian Rice Production		-0.0485
		(0.0862)
Observations	24	24

All variables are in logs. Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01

Table 14: Probability of Any Post-secondary Education against Total Fish Catch and against High and Low Mercury Fish Catches around Birth. Individuals Born in Coastal Municipalities in 1953-1972 and residing in any type of Municipality, Coastal or Landlocked, in 1993. Municipality and year fixed effects estimates (Colombian Census of 1993)

	(1) FE	(2) IV-FE	(3) FE	(4) IV-FE
Fish Catch around Birth (Thousand Tonnes) X	-0.0003	-0.0003		
Fraction of Municipality Boundary that is Coastline	(0.0003)	(0.0004)		
High Mercury Fish Catch around Birth (Thousand Tonnes) X			-0.0024	-0.0030*
Fraction of Municipality Boundary that is Coastline			(0.0018)	(0.0018)
Low Mercury Fish Catch around Birth (Thousand Tonnes) X			0.0012*	0.0019***
Fraction of Municipality Boundary that is Coastline			(0.0007)	(0.0006)
Male	-0.0053***	-0.0053***	-0.0053***	-0.0053***
	(0.0019)	(0.0019)	(0.0019)	(0.0019)
Black	-0.0379***	-0.0379***	-0.0379***	-0.0379***
	(0.0075)	(0.0075)	(0.0075)	(0.0075)
Indigenous	-0.0778***	-0.0778***	-0.0777***	-0.0776***
	(0.0198)	(0.0198)	(0.0198)	(0.0198)
Observations	812128	812128	812128	812128
Number of Municipalities	44	44	44	44
Kleibergen-Paap rk LM statistic		20.001		20.065
Kleibergen-Paap rk LM statistic *p*-value		0.010		0.005
Hansen J statistic		9.621		6.048
Hansen J statistic *p*-value		0.211		0.418

Dependent variable: Dichotomous variable taking the value of one if the individual has any post-secondary education. Independent variables measured around birth are four year moving averages (1,1,2): the year before birth and the three first years of life. FE and IV-FE stacked cross-section cohort regressions of individuals in the age range 21-40. IV instruments are anomalies in the temperature of the sea surface: Number of three months moving averages centered around each month in the year above (below) the anomaly threshold: +0.5 (-0.5) Celsius in the Pacific and +0.18 (-0.18) Celsius in the Caribbean, mean of the positive (negative) temperature changes that were anomalous during the corresponding three months moving averages that year. Since the threshold varies by ocean, we interact each of these variables with an indicator for Atlantic coast. All variables are also interacted with the fraction of the municipality border that is coastline. Thus we have 8 instruments. Standard errors clustered at the municipality of birth level in parentheses. * p<0.10, ** p<0.05, *** p<0.01

Table 15: Probability of Working in a Blue-Collar Occupation as an Adult Aged 21-40 against Total Fish Catch and against High and Low Mercury Fish Catches around Birth. Individuals Born in a Coastal Municipality in 1953-1972 and residing in any type of Municipality, Coastal or Landlocked, in 1993. Municipality and year fixed effects estimates (Colombian Census of 1993)

	(1) FE	(2) IV-FE	(3) FE	(4) IV-FE
Fish Catch around Birth (Thousand Tonnes) X Fraction of Municipality Boundary that is Coastline	0.0008** (0.0004)	0.0013*** (0.0005)		
High Mercury Fish Catch around Birth (Thousand Tonnes) X Fraction of Municipality Boundary that is Coastline			0.0054** (0.0024)	0.0058* (0.0029)
Low Mercury Fish Catch around Birth (Thousand Tonnes) X Fraction of Municipality Boundary that is Coastline			-0.0017* (0.0010)	-0.0016 (0.0014)
Male	0.2052*** (0.0054)	0.2052*** (0.0054)	0.2052*** (0.0054)	0.2052*** (0.0054)
Black	-0.1468*** (0.0275)	-0.1468*** (0.0275)	-0.1469*** (0.0275)	-0.1469*** (0.0275)
Indigenous	-0.0235** (0.0088)	-0.0234** (0.0088)	-0.0236** (0.0088)	-0.0236** (0.0088)
Observations	826852	826852	826852	826852
Number of Municipalities	44	44	44	44
Kleibergen-Paap rk LM statistic		20.443		20.197
Kleibergen-Paap rk LM statistic *p*-value		0.009		0.005
Hansen J statistic		8.905		7.916
Hansen J statistic *p*-value		0.260		0.244

Dependent variable: Dichotomous variable taking the value of one if the individual occupation is blue collar: working class, agricultural day laborers and domestic employees. Independent variables measured around birth are four year moving averages (1,1,2): the year before birth and the three first years of life. FE and IV-FE stacked cross-section cohort regressions of individuals in the age range 21-40. IV instruments are anomalies in the temperature of the sea surface: Number of three months moving averages centered around each month in the year above (below) the anomaly threshold: +0.5 (-0.5) Celsius in the Pacific and +0.18 (-0.18) Celsius in the Caribbean, mean of the positive (negative) temperature changes that were anomalous during the corresponding three months moving averages that year. Since the threshold varies by ocean, we interact each of these variables with an indicator for Atlantic coast. All variables are also interacted with the fraction of the municipality border that is coastline. Thus we have 8 instruments. Standard errors clustered at the municipality of birth level in parentheses. * p<0.10, ** p<0.05, *** p<0.01

Table A1: Municipalities with at least one weather station by coast and year (data source: IDEAM)

Year	Atlantic Coast (Number of Municipalities = 31)	Pacific Coast (Number of Municipalities = 16)
1950	3	2
1951	4	2
1952	4	2
1953	5	2
1954	7	2
1955	7	2
1956	8	2
1957	8	2
1958	12	2
1959	13	2
1960	14	3
1961	14	3
1962	15	3
1963	16	5
1964	17	3
1965	18	4
1966	17	6
1967	18	7
1968	17	5
1969	17	8
1970	17	8
1971	18	7
1972	20	7
1973	23	7
1974	26	7
1975	26	7
1976	26	7
1977	26	7
1978	25	7
1979	25	7
1980	26	7
1981	26	7
1982	26	7
1983	26	10
1984	26	10
1985	26	10
1986	26	10
1987	26	10
1988	27	10
1989	27	10
1990	27	10
1991	27	10
1992	27	10
1993	28	11
1994	28	11
1995	28	11
1996	28	11
1997	28	11
1998	28	11

Table A2: Probability of Any Post-secondary Education against Total Fish Catch and against High and low Mercury Fish Catches around Birth. Individuals Born in a Coastal Municipality in 1953-1972 and *Still Residing in the Same Coastal Municipality in 1993*. Municipality and year fixed effects estimates (Colombian Census of 1993)

	(1) FE	(2) IV-FE	(3) FE	(4) IV-FE
Fish Catch around Birth (Thousand Tonnes) X Fraction of Municipality Boundary that is Coastline	-0.0003	-0.0002		
	(0.0003)	(0.0004)		
High Mercury Fish Catch around Birth (Thousand Tonnes) X Fraction of Municipality Boundary that is Coastline			-0.0025	-0.0033**
			(0.0017)	(0.0016)
Low Mercury Fish Catch around Birth (Thousand Tonnes) X Fraction of Municipality Boundary that is Coastline			0.0014*	0.0022***
			(0.0007)	(0.0006)
Male	-0.0118***	-0.0118***	-0.0118***	-0.0118***
	(0.0020)	(0.0020)	(0.0020)	(0.0020)
Black	-0.0213*	-0.0213*	-0.0213*	-0.0213*
	(0.0122)	(0.0122)	(0.0122)	(0.0122)
Indigenous	-0.0396***	-0.0396***	-0.0394***	-0.0393***
	(0.0041)	(0.0041)	(0.0040)	(0.0040)
Observations	556165	556165	556165	556165
Number of Municipalities	43	43	43	43
Kleibergen-Paap rk LM statistic		18.654		15.572
Kleibergen-Paap rk LM statistic *p*-value		0.017		0.029
Hansen J statistic		9.072		8.985
Hansen J statistic *p*-value		0.248		0.174

Dependent variable: Dichotomous variable taking the value of one if the individual has any post-secondary education. Independent variables measured around birth are four-year moving averages (1, 1, 2): the year before birth and the three first years of life. FE and IV-FE stacked cross-section cohort regressions of individuals in the age range 21-40. IV instruments are anomalies in the temperature of the sea surface: Number of three months moving averages centered around each month in the year above (below) the anomaly threshold: +0.5 (-0.5) Celsius in the Pacific and +0.18 (-0.18) Celsius in the Caribbean, mean of the positive (negative) temperature changes that were anomalous during the corresponding three months moving averages that year. Since the threshold varies by ocean, we interact each of these variables with an indicator for Atlantic coast. All variables are also interacted with the fraction of the municipality border that is coastline. Thus we have 8 instruments. Standard errors clustered at the municipality of birth level in parentheses. * p<0.10, ** p<0.05, *** p<0.01

Table A3: Probability of Working in a Blue-Collar Occupation as an Adult Aged 21-40 against Total Fish Catch and against High and Low Mercury Fish Catches around Birth. Individuals Born in a Coastal Municipality in 1953-1972 and *Still Residing in the Same Coastal Municipality in 1993*. Municipality and year fixed effects estimates (Colombian Census of 1993)

	(1) FE	(2) IV-FE	(3) FE	(4) IV-FE
Fish Catch around Birth (Thousand Tonnes) X Fraction of Municipality Boundary that is Coastline	0.0009**	0.0014***		
	(0.0003)	(0.0004)		
High Mercury Fish Catch around Birth (Thousand Tonnes) X Fraction of Municipality Boundary that is Coastline			0.0050***	0.0052**
			(0.0018)	(0.0023)
Low Mercury Fish Catch around Birth (Thousand Tonnes) X Fraction of Municipality Boundary that is Coastline			-0.0014	-0.0009
			(0.0008)	(0.0010)
Male	0.1984***	0.1984***	0.1984***	0.1984***
	(0.0081)	(0.0081)	(0.0081)	(0.0081)
Black	-0.0756**	-0.0755**	-0.0756**	-0.0756**
	(0.0300)	(0.0300)	(0.0299)	(0.0299)
Indigenous	-0.0255***	-0.0253***	-0.0257***	-0.0256***
	(0.0078)	(0.0078)	(0.0078)	(0.0078)
Observations	566631	566631	566631	566631
Number of Municipalities	43	43	43	43
Kleibergen-Paap rk LM statistic		18.734		15.978
Kleibergen-Paap rk LM statistic *p*-value		0.016		0.025
Hansen J statistic		7.666		5.870
Hansen J statistic *p*-value		0.363		0.438

Dependent variable: Dichotomous variable taking the value of one if the individual occupation is blue collar: working class, agricultural day laborers and domestic employees. Independent variables measured around birth are four year moving averages (1, 1,2): the year before birth and the three first years of life. FE and IV-FE stacked cross-section cohort regressions of individuals in the age range 21-40. IV instruments are anomalies in the temperature of the sea surface: Number of three months moving averages centered around each month in the year above (below) the anomaly threshold: +0.5 (-0.5) Celsius in the Pacific and +0.18 (-0.18) Celsius in the Caribbean, mean of the positive (negative) temperature changes that were anomalous during the corresponding three months moving averages that year. Since the threshold varies by ocean, we interact each of these variables with an indicator for Atlantic coast. All variables are also interacted with the fraction of the municipality border that is coastline. Thus we have 8 instruments. Standard errors clustered at the municipality of birth level in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

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