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**Climate Change and Production Risk in Chinese
Aquaculture**

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CLIMATE CHANGE AND PRODUCTION RISK IN CHINESE AQUACULTURE

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CLIMATE CHANGE AND PRODUCTION RISK IN CHINESE AQUACULTURE

Abstract:

Drawing on the method developed by Just and Pope (1978, 1979), this paper separately analyzes the marginal contributions of both regular input factors and climate factors to mean output and to production risk in Chinese inland aquaculture. Furthermore, the net change in output following a 1°C increase in annual average temperature will be determined.

According to the results obtained, the impending changes in global climate will have both positive and negative impacts. While an increment in annual average temperatures will increase mean output and decrease production risk, an increase in temperature variability will reduce mean output and cause a higher level of production risk. The corresponding measures of precipitation however have no significant impact on mean output and production risk. Finally, a 1°C increase in annual average temperature is, *ceteris paribus*, likely to increase national mean output by 1.47 million tons.

Keywords: Aquaculture, climate change, production risk, China

JEL Classification: Q1, Q54

1 Introduction

Fishery is one of the most important sub-sectors of Chinese agriculture. After having experienced several decades of substantial growth rates, China now is the world leader in terms of fish output. Made possible by favorable natural conditions, such as an extensive shoreline of more than 30,000 km and a freshwater surface area of around 17.5 million ha (Song, 1999), this is true for both wild-captured fish and for farmed fish from Chinese aquaculture, which produces around two-thirds of global fish farming output (Delgado et al., 2003).

Moreover, given that the global annual output of capture fisheries has been stagnant at around 90.5-94.6 million tons¹ between 2002 and 2006 and that most of the recent growth in global fish output can thus be attributed to aquaculture, which grew by nearly 28% over the same period thereby reaching an output of 51.7 million tons in 2006 (FAO, 2009), the enormous importance of aquaculture in general and of the Chinese aquaculture sector in particular for supplying food fish to satisfy the growing Chinese domestic and also the international demand becomes obvious. According to the statistics² (National Bureau of Statistics of China, 2008), the value of Chinese fishery output has on the one hand substantially increased from 10.9 billion yuan in 1978 to 445.8 billion yuan in 2007 (at 2007 prices), which means that it has risen to more than 40 times its original value over the course of 30 years. On the other hand, after the share of fishery in total agricultural output at first increased quickly from only 1.6% in 1978 to about 10.9% in 2000, it has since then been slightly shrinking. Nevertheless, the share is still above 9%. Food from aquaculture also plays important roles in the daily life of the Chinese people. Studies show that the expenditures on aquaculture products amount to about 3% and 10% of the total expenditures on food in rural and urban areas, respectively (Yu and Abler, 2009; Liao and Chern, 2007).

¹ Excluding the highly variable catch quantities of anchoveta.

² See Figure 1 in the appendix.

Since not only capture fisheries but also aquaculture operations are very vulnerable to climate conditions, the impending changes in global climate cause the future development of Chinese (and global) fish farming to be highly uncertain. In the current literature, both positive and negative influences on aquaculture have been discussed, which can mostly be attributed either directly or indirectly to changes in temperatures or precipitation patterns. Among the most frequently anticipated possible negative impacts that affect fish directly are an increased degree of heat stress for fish following the warming of water habitats, an increased demand for oxygen under conditions of limited supply, an aggravated toxicity of widespread pollutants in warmer waters and a higher incidence of diseases (Ficke et al., 2007). Other factors affecting fish production through their impact on water habitats or more generally on production conditions include a decreased oxygen solubility of warmed water, water acidification, accelerated eutrophication and stratification, an uncertain future water supply following changes in precipitation patterns, an increased incidence of extreme climatic events, which might kill cultured fish populations or destroy other productive assets, or an increased degree of salt water intrusion as a result of rising sea levels (De Silva and Soto, 2009; Ficke et al., 2007). Furthermore, climate impacts, which negatively affect populations and catch quantities of certain wild pelagic fish, such as anchoveta, could also affect the production of carnivorous fish species in aquaculture because the latter are commonly fed making extensive use of fish meal and fish oil produced from wild fish (Naylor et al., 2000).

However, according to Brander (2007), certain positive effects are likely as well. A global warming could make it possible to set up aquaculture operations in regions that formerly were too cold or to benefit from an expansion of production made possible by an extended frost-free season. In addition, some fish species might experience accelerated growth along with an improved ability to convert feed.

In the literature just discussed, the focus is on potential fish output under changed environmental conditions, in other words on expected changes in mean output. It has however been suggested that aquaculture, similar to other primary industries, is subject to considerable production risk (output risk) because it is frequently affected by stochastic shocks after operators have already decided upon their input use (Asche and Tveterås, 1999). Both endogenous and exogenous factors could cause or affect the resulting uncertainty in output levels. Among the major exogenous drivers of production risk in aquaculture are climate factors because these factors not only experience gradual changes in their mean values as a result of global climate change but also generally display considerable and partly unpredictable inter-annual variability. Moreover, it is known that the applied quantities of regular input factors like land or labor are also relevant for the level of output risk inherent in an agricultural production process (Just and Pope, 1979; Kumbhakar and Tsionas, 2008; Holst et al., 2010).

According to the latest IPCC report, it is projected that East Asia could experience a median increase in annual average temperatures of around 3.3°C until 2100, along with possible increases in total annual precipitation and higher levels of climatic variability in terms of an increased incidence of extreme weather events, which could lead to more droughts and floods (Christensen et al., 2007). In light of the possible impacts of climate change on mean output and production risk of aquaculture operations, it thus is of crucial importance to determine, in which way Chinese aquaculture output will be affected. Despite this fact, to the best of our knowledge, no rigorous production economic analysis taking into account the contributions of both regular inputs and climate factors to the mean of output (i.e. the expected output) and to the level of production risk has been conducted on the present subject

yet³. Hence, the present paper is intended to remedy this deficit and thereby provide new insights with respect to the question of whether China will be adversely affected by the current changes in the world climate or whether it might even become a net beneficiary. In addition, the net benefit, in terms of the change in output quantity, of a 1°C increase in annual average temperature is calculated.

2 Empirical Analysis

2.1 Econometric Approach

Two distinct approaches to estimating the economic impacts of climate change on agriculture have been used in earlier studies, the production function and the Ricardian approach. For the purpose of the present study, the former approach has been opted for because it holds a number of advantages over the latter in this case. The Ricardian approach aims at analyzing the productivity of agricultural land, which can be measured for example as net revenue (Mendelsohn et al., 2003; Mendelsohn, 2009), profit (Deschênes and Greenstone, 2007), land value (Féres et al., 2008) or land rent (Lippert et al., 2009), by using a set of climate and other exogenous variables as explanatory variables. However, China possesses neither a functioning free market for agricultural land nor for water resources, so that all methods analyzing variables such as land rent or land value of regular farm land and of water areas are inherently problematic. Also, the Ricardian approach is prone to suffering from the omitted variables bias because unmeasured factors such as the quality of land (and waters) could not only codetermine land values (or rents) and output quantities but could also lead to endogeneity in regressions due to a possible correlation with climate variables (Deschênes and Greenstone, 2007). Moreover, the Ricardian approach, as it has been used in earlier studies (e.g. Mendelsohn et al. (2003), Mendelsohn (2009) or Deschênes and Greenstone (2007), is

³ Indeed, in their studies on Norwegian salmon farming, Asche and Tveterås (1999), Tveterås (1999) and Tveterås and Wan (2000) analyze mean output as well as production risk and acknowledge the influence of weather factors but do not consider the latter as explanatory variables in their regressions.

under certain conditions very similar to the production function approach. If one were to consider a vector of exogenous variables, which consists of climate factors and regular inputs, as regressor for the Ricardian approach and would furthermore assume that input decisions (and therefore also production costs) are not determined by weather factors because input decisions have to be made before farmers know the weather conditions during a season, the Ricardian approach would basically be reduced to a production function analysis.

While the production function approach itself has been criticized for not being able to account for farmers' possibilities to adapt, thereby potentially biasing the estimation results regarding climate variables (Deschênes and Greenstone, 2007), it nevertheless seems justified, particularly because it offers the possibility of analyzing the output risk stemming from changes in climate factors, which is one of the main goals of this study.

2.2 Elementary Model

All steps of the following analysis of Chinese aquaculture are based on the Cobb-Douglas production function, which has frequently been used in studies on agriculture before (examples include Hayami, 1969; Echevarria, 1998; and Hu and McAleer, 2005), because it has often been found to yield reasonable fits to production processes in the real world. In the present context, the Cobb-Douglas production function takes the following form:

$$(1) \quad y_{it} = A_i \left(\prod_{k=1}^K x_{kit}^{\alpha_k} \right) e^{\varepsilon} ,$$

where y_{it} is the aquaculture output in province i during year t , A_i captures the fixed effects, x_{kit} is the quantity of input factor k used in province i during year t and α_k is the input intensity parameter of input k . After log-linearizing the above equation and estimating it, α_k will be interpreted as the elasticity of output with respect to input k .

Usually, when the panel units are considerably heterogeneous entities, which can be confirmed with respect to China's provinces, a fixed effects estimation would be appropriate. It has however been noted by Just and Pope (1979) that output risk causes heteroskedasticity. Furthermore, testing reveals the presence of first-order serial correlation. Since both of these factors would lead to inefficient (but not inconsistent) estimates, an FGLS estimator, which is able to compensate both issues (Wooldridge, 2002), is preferred. For the purpose of comparison, the above model will be estimated both with and without consideration of climate factors as explanatory variables. Even though they cannot be controlled by farmers (or aquaculture operators), introducing climate influences in the same way as regular inputs is a common approach in the literature (e.g. Zhang and Carter, 1997).

2.3 Output Risk

As has been discussed earlier in this paper, output risk can appear as heteroskedasticity in the production function framework chosen for this study. Just and Pope (1978) observed that many of the commonly used stochastic production function specifications are inappropriate for analyzing production risk because they only allow for positive marginal contributions to the variance. Thus, Just and Pope (1978, 1979) developed a three-stage estimation procedure that makes it possible to analyze marginal contributions to mean output and to production risk separate from each other. This method will be applied in the present study in order to analyze both aspects of production in the case of Chinese aquaculture. With some slight alterations for panel-data estimation, the flexible (or generalized) production function proposed by Just and Pope takes the following form:

$$(2) \ y_{it} = f(\mathbf{X}_{it}) + \left(\sqrt{h(\mathbf{R}_{it})} \right) \varepsilon_{it} \ ,$$

where y_{it} again represents the aquaculture output of province i in year t . The output is now determined by a function $f(\mathbf{X}_{it})$, which can be called “mean production function”, and a function $h(\mathbf{R}_{it})$, which can be called “risk production function” (Asche and Tveterås, 1999). Both are specified as Cobb-Douglas functions. \mathbf{X}_{it} is a vector of independent variables (regular input factors and climate variables in this case) pertaining to province i in year t . \mathbf{R}_{it} in turn a vector of independent variables, that is likely to be decisive for the emergence of output risk. Even though these two vectors do not have to be identical, they will comprise the same set of regular inputs and climate variables in this study. Finally, ε_{it} is a standard normal distributed error term.

An important property of this specification is that the expected value of output, or in other words the mean output, is not determined by means of the same function that is used to determine the variance:

$$(3) \quad E(y_{it}) = f(\mathbf{X}_{it})$$

$$(4) \quad V(y_{it}) = h(\mathbf{R}_{it}).$$

The above-mentioned three-stage procedure proposed by Just and Pope (1979), which makes it possible to estimate equation (2) as a non-linear panel data model, involves (i) estimation of the mean production function using the method of non-linear OLS⁴, (ii) fixed effects estimation of the risk production function, where risk is determined by subtracting from the predicted values of stage (i) the observed values from the data set, and (iii) repeating the estimation of the mean production function using the obtained contributions to output risk as weights for a generalized non-linear OLS estimation.

It should however be kept in mind that China, as a large country, is characterized a number of heterogeneities, for example as it comes to geography, social and economic

⁴ For the purpose of this estimation, the second term on the right-hand side of equation (2) is just treated as a heteroskedastic error term.

development or climate. If the influences of such factors, which are not observed in the model, significantly affect the province-level output figures with respect to aquaculture, it would be necessary to introduce provinces dummies on the first and last stage of the above procedure that capture these influences. In order to determine the necessity of doing so, an F-Test will be applied, which compares the results of a mean production function (stage (iii)) with dummy variables included to those obtained from a mean production function without dummy variables.

2.4 Quantification of the Impact of Climate Change

The elasticities of mean output and of production risk with respect to the different climate factors, which can be estimated using the procedure presented in the preceding chapter, also allow quantifying the impact of a given marginal change in a climate factor on total output. Given that a gradual warming is one of the most certain changes in global climate expected for the future, it seems of particular significance to determine the effect of a 1°C increase in annual average temperature on mean fish output at the national level. The result will likely hold important implications for food security in China.

Drawing on equations (2) and (3), the change in quantity can be calculated as follows:

$$(5) \quad q_m = \frac{\partial E(y)}{\partial m} = \frac{\partial f(\mathbf{X})}{\partial m} = \alpha_m \frac{f(\mathbf{X})}{m},$$

where q_m represents the quantity by which mean output increases or decreases following a marginal change in annual average temperature (m) and where α_m is the elasticity of mean output with regard to the annual average temperature.

3 Data

For the purpose of the above analyses, a panel data set comprising the relevant fishery and climate data of 26 Chinese provinces, which covers the time period 1996-2005, has been constructed. In particular, the provincial fishery data provide information on the total weight of fish farm output, the number of fishery boats as well as of laborers, the number of fry stocked and the size of the area under aquaculture. The climate data in turn include monthly observations of temperatures and precipitation quantities. All data are taken from the respective issues of the China Statistical Yearbook (National Bureau of Statistics of China, 1997-2006), the China Agricultural Yearbook (Chinese Ministry of Agriculture, 1997-2006 a), and the Chinese Fishery Yearbook (Chinese Ministry of Agriculture, 1997-2006 b).

While the available data on output, fry, and area used are already specific to inland freshwater aquaculture, the data on labor and boats have to be adjusted. In order to obtain the number of boats used for the purpose of inland fish farming, the number of boats in ocean fishery has in a first step been subtracted from the total number of fishing boats in all of China, leaving only boats in inland fishery. The result has then been multiplied by the ratio of the number of boats used in the course of fish farming to the total number of fishing boats in China. Because data on the number of boats in fish farming were only available for the years from 2005 through 2007, it has been decided to use the average ratio of boats in fish farming to total fishing boats in China over those three years for the above data adjustment. Similarly, so as to arrive at approximate values of the number of laborers active in inland fish farming, the total number of laborers in fish farming has been multiplied by one minus the ratio of the number of laborers in ocean fish farming to the total number of laborers in all of Chinese fish farming. In this case the adjustment factor has been averaged over the period from 1998 through 2001. This simplifying approach to adjusting input data has also been used in other studies on agricultural production such as those of Lin (1992) and Zhang and Carter (1997).

Based on the monthly climate observations, two distinct sets of variables have been constructed. On the one hand, the annual average temperature and the total annual precipitation are calculated in order to analyze the effects of changing mean climate conditions. On the other hand, unpredictable climate variability is likely to play an important role, especially as far as production risk is concerned. Thus, the linear growth trend of each month (January until December) over the time period under consideration (1996-2005) has been calculated for both climate factors (temperature and precipitation). By subtracting from each individual climate observation the value of the linear prediction of the respective month and summing up the absolute values of the differences within each year, it is possible to obtain variables that express to what extent the climate of any given year deviates from what would have to be expected if one were to assume that climate change progresses in a linear way. We use these variables as proxies for the above-mentioned unpredictable climate variability.

Table 2 in the appendix summarizes the available output and input data as well as the climate data on the national level.

4 Results

4.1 Model Comparison

Table 3 in the Appendix contains the estimation results of the different regressions discussed earlier. In total, five models are presented. Model I yields a regular FE (fixed effects) panel estimator. Tests however reveal serial correlation among the error terms in this model. Apart from any risk considerations, this alone warrants the use of an FGLS estimator, which is able to remedy the effects of both serial correlation and heteroskedasticity. Therefore, Model II presents the results of the corresponding FGLS estimation. With respect to model III, the conjecture is acknowledged that the model used up to this point is actually

not correctly specified as long as it does not contain climate variables. Therefore, it is extended by including variables representing the annual average temperature, the total annual precipitation and the variability measures regarding temperature and precipitation discussed in the preceding section. Given that serial correlation is still found to affect the results of this extended model, it is again estimated using the method of FGLS. Finally, Models IV and V are based on the Just and Pope procedure. Both consist of a mean production function as well as a risk production function and differ only in the fact that Model IV is estimated without inclusion of dummy variables representing the individual provinces, while Model V does contain these dummies. In addition to regular (and climate) inputs, all of the above models also feature a linear time trend to capture for example the influences of technological change.

Based on an F-test (F-ratio: 4.1767; p-value: 0.000), the null-hypothesis that the panel units (i.e. provinces) are not significantly different from each other is rejected. Thus, Model V is the preferred specification for the Just and Pope procedure. Comparing the mean production function of this Model (Va) with Model III, it emerges that the obtained estimates are nearly identical with respect to sign and significance. The variable representing the number of boats in production is the only exception. It is positive and highly significant in Model III but not significant in Model Va. Nevertheless, the Just and Pope procedure has a clear general advantage over Models I-III, namely that it allows to separately analyze marginal contributions to mean output and to production risk, whereas these contributions cannot be separated in Models I-III, thereby making their results somewhat less reliable. Consequently, the following exposition is based entirely on Models Va and Vb.

4.2 Mean Output in Chinese Aquaculture

Based on the obtained output elasticities in Model Va (Appendix, Table 3), it can be stated that the area under aquacultures would be of crucial importance for an expansion of

production. With a coefficient of 0.6645 it has by far the highest marginal effect of all conventional inputs considered here. This result, which is significant at the 1%-level, does not come as a surprise given that land can be considered the most elementary input to the majority agricultural production processes. Furthermore, given that China has a favorable natural endowment for inland aquaculture and still features excellent possibilities for expanding it even further (Song, 1999), it seems reasonable to assume that additional fresh water areas for fish cultivation are still available in good quality and that the associated marginal impact on mean output is thus comparatively high.

The output elasticities with respect to both labor and fry⁵ are also highly significant but are both much smaller in their magnitude. While labor reaches a coefficient estimate of 0.1523, the corresponding value for fry is 0.0618. In general, it has been observed that certain rural regions in China feature a substantial labor surplus (Bowlus and Sicular, 2003), which would imply a very low marginal product of an incremental unit of labor. However, it is also a fact that the degree of intensity in fish farming varies widely among the Chinese provinces. In particular, in the less developed provinces where capital inputs, infrastructure and highly skilled personnel are relatively more scarce, the prevalent mode of aquaculture is extensive production using comparatively low quantities of inputs as compared to the more developed provinces (Chen et al., 1995). Consequently, it should be possible to increase mean output by means of intensifying production. According the results presented here, one way of achieving this is to increase the labor input *ceteris paribus*. A similar line of reasoning applies in the case of fry input. However, increasing the quantity of fry stocked in the beginning of a season with water area held constant, increases the density of a fish population and thereby strengthens forces that have a negative impact on mean fish output. Among these forces are an increased

⁵ The rearing period of fish depends on the species and the climate zone in which the aquaculture operation is located but it can generally be stated that it is longer than one year for many fish species, which are common in Chinese aquaculture. Silver carp, Bighead carp or Crucian carp for example have to be reared for two years before they have gained sufficient weight (Jian, 1985). Thus, instead of using the quantities of fry stocked in the production year, the corresponding one-year lag values are employed for the regressions instead.

competition for food, reduced oxygen levels in the water, an increased likelihood diseases being transmitted within the population and others (Ficke et al., 2007; De Silva and Soto, 2009). Therefore it is reasonable to find the output elasticity with respect to fry to be below that of other inputs.

The variable representing the use of boats in fish farming in turn is not significant, which might be related to the circumstance that only some aquaculture practices, like those relying on rivers, reservoirs or larger lakes, actually involve the use boats, whereas others, particularly those conducted in artificial basins or shallow natural ponds, do not require the use of boats. The fact that aquaculture in China is conducted in a variety different natural settings comprising to some extent all of the above categories (Song, 1999) and that this variable might thus at least partly capture the influences from other forms of capital equipment, which could not be considered here, seems to be a valid explanation for the insignificant result.

Focusing now on the core issue of this paper, namely the marginal contributions of the different climate factors, it surprisingly emerges that only the two temperature variables are significant (1%-level) but not the variables related to precipitation. This is unexpected because the literature review in Section 1 suggested that changes in the quantity of precipitation or its patterns could have a non-negligible impact on mean output, particularly by influencing the water availability in lentic systems and in artificial environments but also in lotic ecosystems, for example when a river's discharge is strongly affected. Inspection of the development of the national average of the total annual precipitation variable over time does however reveal no significant linear trend (Appendix, Table 1 and Figure 3). In light of this, it might be possible that the changes in precipitation quantities over the time period under consideration in this study (1996-2005) have not yet been strong enough to cause any significant impact on aquaculture at the national level.

Regarding the variability of precipitation, it might be case that positive deviations in individual months within a year are at least partly be compensated by negative ones in other months and vice versa. Both positive and negative deviations from mean conditions would add to climate variability as it is measured by the present indicator, which can consequently not take compensations into account. This consideration seems to explain well why no significant impact of precipitation variability could be obtained.

In the case of temperature variability however this is different. A positive deviation of temperature in one month cannot compensate a negative deviation in the subsequent month because large bodies of water take too long for warming sufficiently and small bodies of water also cool down more rapidly. Thus, both positive and negative deviations of temperature can be considered to be adverse events if they warm or cool ponds, lakes, rivers and other bodies of water sufficiently to have a negative impact on animals raised in aquaculture (i.e. if the lethal temperature limits of the individual species are reached). Because fish are poikilothermic, which means that their body temperature depends on the temperature of the water, their entire physiology (e.g. in terms of growth, metabolism or reproduction) will be affected by temperatures that deviate strongly from those mean conditions fish are adapted to (De Silva and Soto, 2009). Consequently, a year with high sum of absolute monthly deviations from the linear growth trend should be characterized by a lower mean output and a further increment in this measure should also have a negative impact at the margin, which would explain the highly significant output elasticity of -0.0659 found in this study.

The output elasticity with respect to the annual average temperature in turn is positive (1.1081) and significant at the 1%-level. As lined out, the growth of fish depends on the ambient water temperature with the growth rate generally being positively stimulated by higher temperatures until the optimal level is exceeded. After that fish growth decreases again (Ficke et al., 2007). Common carp for example, which one of the most commonly cultivated

fish species in China (Song, 1999), can survive at temperatures ranging from 0-35.7°C and feature a comparatively high optimal temperature range of 26.7-29.4°C (Ficke et al., 2007). While certainly not all fish species cultured across China's different climate zones prefer such warm water, it nevertheless shows that gradual and limited increases in annual average temperature can potentially have a positive impact on mean output. Further support for this can be seen in the circumstance that higher annual average temperatures tend to be associated with an extended growing season allowing fish to grow for a longer time before being caught or alternatively to raise more generations of fish per year.

4.3 Production Risk in Chinese Aquaculture

The risk production function, as proposed by Just and Pope (1978, 1979), makes it possible to estimate risk elasticities with respect to both conventional inputs and climate factors. The results obtained by applying this procedure to Chinese aquaculture are presented in Table 3 in the appendix (Model Vb). Judging by the R-squared of this model, it emerges that much less of the variance of this model can be explained by the input factors under consideration, which should be attributable to the fact that the level of production risk is likely subject to numerous unobserved and potentially interacting external forces. Nevertheless, some influential determinants of production risk could be determined.

The only conventional input reaching a high level of significance is labor (5%-level), which features a coefficient of 0.7012. The reason for this might be rooted in the above-mentioned fact that, particularly in the rural areas of less developed provinces, highly qualified labor is relatively scarce (Chen et al., 1995), and hiring additional laborers with low levels of qualification certainly contributes positively to the risk present in a sensitive production process such as aquaculture. Additionally, raising the number of laborers

employed is likely to increase the difficulty of exactly coordinating the efforts of all laborers, which might also create a certain positive contribution to production risk.

The fact that only one of the conventional input factors is significant and even has a risk-increasing impact at the margin has two important implications. On the one hand, aquaculture in China is characterized by increasing risk to scale, which means that if all input factors are simultaneously increased by a common factor, the level of production risk will increase as well. On the other hand, it is also implied that none of the input factors considered in the present analysis is suitable for compensating production risk emanating from other sources (e.g. climate factors or diseases).

Among the climate influences analyzed, again only those stemming from the temperature-related variables are significant. With a coefficient estimate of -4.3058 the annual average temperature has a very strong influence on production risk at the margin, which is significant at the 5%-level. Possible factors supporting this result are for example the lower risk of strong adverse frost events or a longer growing season combined with accelerated fish growth resulting in better possibilities for conducting more than one production cycle within one year in regions that formerly were too cold for this mode of production. The latter would allow higher levels of production even if individual generations of fish are adversely affected by some sort of unexpected event. Risk-increasing factors related to an increase in annual average temperatures like a higher probability of the emergence and spread of diseases among fish are obviously not strong enough to cause a positive risk contribution of this variable.

Similar to the pattern of results obtained with respect to the mean production function, it again emerges that temperature variability adversely affects aquaculture. The highly significant (1%-level) coefficient estimate of 0.6117 is indicative of a strong risk-increasing marginal impact of this climate variable, which is the result that was to be expected. Since shallow ponds and other small bodies of water, in which inland aquaculture is often

conducted, cool or warm rapidly, unusually low or high temperatures could subject fish to considerable temperatures stress, even if these conditions only prevail for short durations of time. In particular, it has been observed that even brief heat spells can cause a degree of warming sufficient to kill large shares of fish populations.

Why the climate variables related to precipitation again do not reach conventional levels of significance is unclear. One possible explanation with respect to the variability measure might however again be that this particular indicator is, by virtue of its construction, not able to capture the partial compensation of negative deviations in individual months by positive deviations in other months or vice versa, which is made possible by the fact that water accumulates in the environment (e.g. in lakes, rivers or in the soil).

4.4 Impact of Climate Change on Mean Output

Employing equation (5) and the result obtained with respect to the annual average temperature in the mean production function (Appendix, Table 3, Model Va), the impact of a 1°C increase in annual average temperature can be calculated. The average of the annual average temperature in the capital cities of the 24 province, which have been considered in this study, was 14.6°C in 2005 (National Bureau of Statistics of China, 2006) while the total national output of inland fish farms amounted to 19.31 million tons (compare Table 2 in the Appendix). Given an elasticity of mean output with respect to the annual average temperature of 1.1081, the increase in mean output would amount to:

$$q_m = \alpha_m \left(\frac{f(\mathbf{X})}{m} \right) = 1.1081 \left(\frac{19.31}{14.6} \right) \approx 1.47 \text{ million tons.}$$

In China, grass carps and carps are among the two main types of freshwater fish. Their average price in the country's 36 major cities in 2005 was 10.25 yuan/kg, which implies that the marginal value of the above temperature change amounts to 15.07 billion yuan.

5 Conclusions

The present study has made several novel contributions to the current literature on inland aquaculture in China. First, a newly constructed provincial-level panel data set has been used to estimate the output elasticities of aquaculture with respect to labor, fry, boats and water area. Second, because climate factors strongly affect many primary production processes, including aquaculture, a number of climate variables (annual average temperature, total annual precipitation and the variability of temperature and precipitation) have additionally been considered as inputs. Third, the estimation procedure by Just and Pope (1978, 1979) has been applied to separately analyze the marginal contributions of all of the above inputs to mean output and to output risk. Fourth, the monetary benefit of a 1°C increase in annual average temperature has been determined.

To sum up and interpret the obtained results, it seems that Chinese inland aquaculture, which has already grown rapidly over the past years, is likely to be able to increase its output in the foreseeable future. In light of the growing pressure on wild fish populations, this will become increasingly important for a stabilization and expansion of Chinese and global fish output. Except for the use of boats, all other conventional input factors have a positive impact on mean output at the margin. It also emerges that, judged by its output elasticity, increasing the water area used for aquaculture has the highest potential for increasing output, which is to say that an extensive mode of production currently seems to be preferable for China as a whole. However, since inland waters are in constant supply and can be expanded only to a very limited extent, it will sooner or later become necessary to resort to a more intensive mode of production. Based on the positive marginal contributions to mean output, increasing the number of fry stocked and of laborers employed would be a viable strategy for this but labor also has a negative impact on production because it increases the level of output risk. Thus, in

the case of labor, the benefits of an increased mean output have to be weighed against the losses from an increased risk level.

Similar contradictions emerge from the results with respect to climate influences. While an increase in annual average temperature would have a strong positive impact on mean output at the margin and would simultaneously also reduce the level of production risk, an increase in temperature variability would be associated with a negative marginal contribution to mean output and would at the same time increase output risk. Since most current climate projections forecast both an increase in annual average temperatures in East Asia stemming from a general global warming as well as a higher degree of climate variability, the Chinese aquaculture sector will likely be subject to the contradicting influences of these two aspects of temperature both with respect to mean output and with respect to output risk. Nevertheless, judged by the magnitude of the estimated coefficients, the positive impacts of an increase in annual average temperature should outweigh the negative effects of an increase in temperature variability, at least in the short run. In other words, in terms of its aquaculture output China could become a net beneficiary of climate change in the near future. The increase in the output of inland fish farming following a 1°C increase in annual average could be as high as 1.47 million tons.

However, this result should be interpreted with caution. It is well known fish can only benefit from higher temperatures to a limited extent. Once the upper limit of their optimal temperature range has been exceeded, the marginal effect of further increments in temperature will turn negative. Thus, in the short run Chinese aquaculture might be able realize additional output as a consequence of the ongoing changes in the global climate but in the long run it will likely face increasingly negative impacts and will have to adapt if output is to be stabilized. This situation will be aggravated by the fact that none of the conventional output factors considered in this study has a significant negative impact on output risk, which means

that none of them can be used to compensate the risk stemming from climate influences. Consequently, future research should be focused on working out suitable adaptation measures to enable aquaculture operations in China and elsewhere to cope with the likely impending effects of a changing climate.

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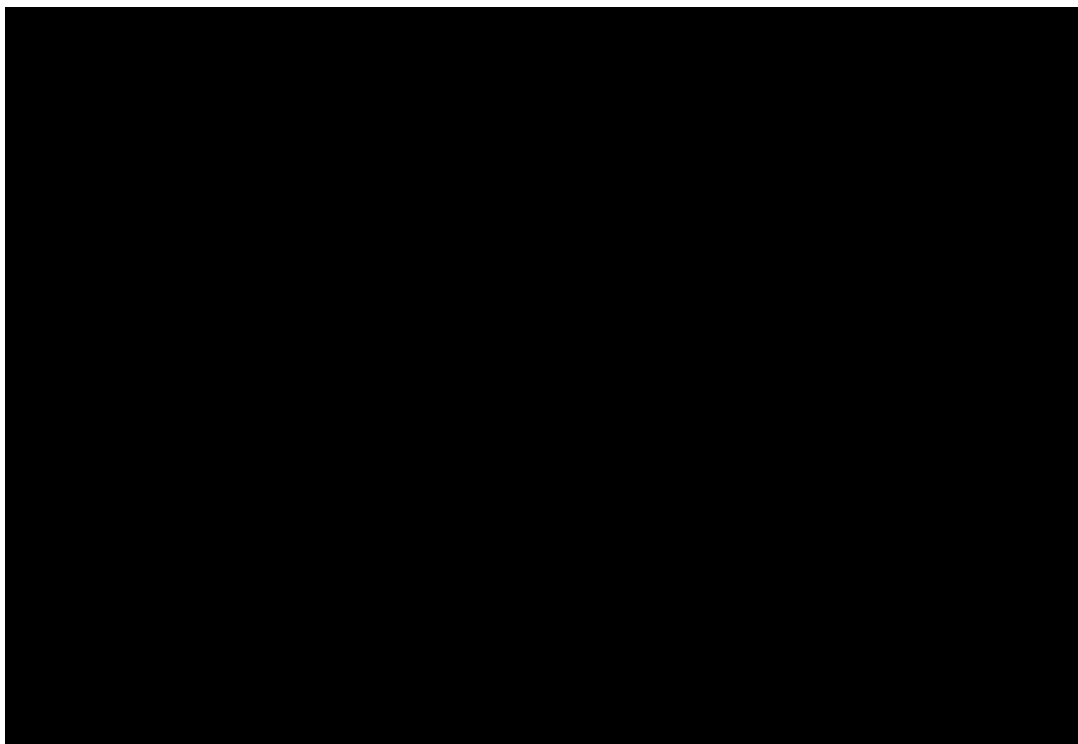
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Appendix

Figure 1: Fishery Output in China



Data: National Bureau of Statistics of China (2008)

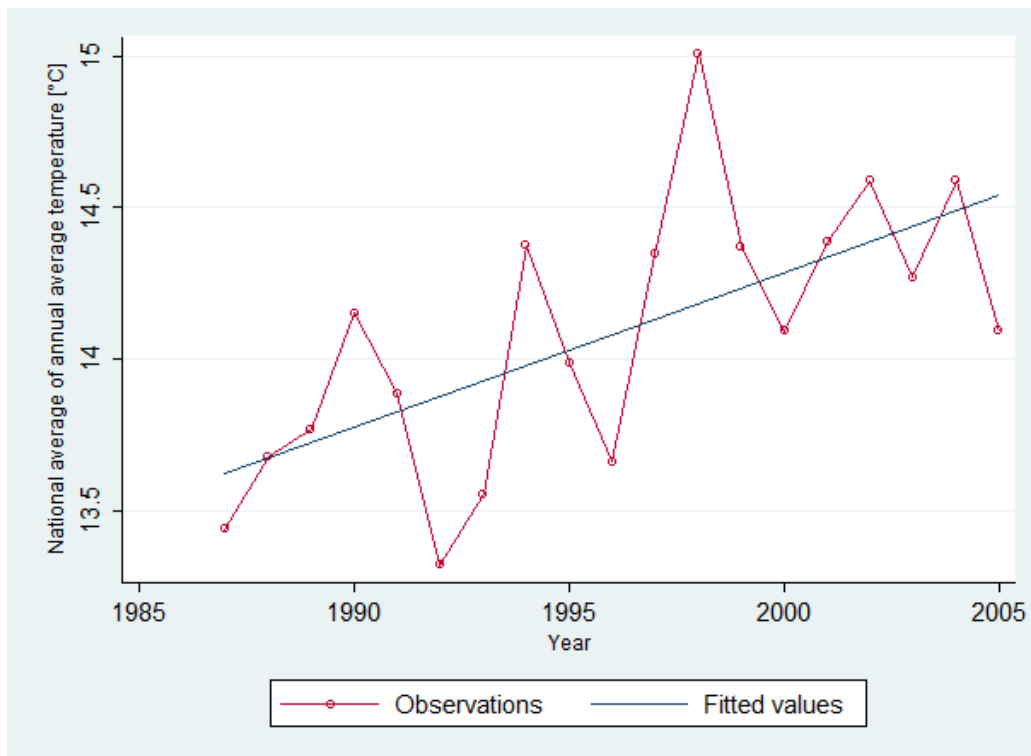
Table1: Linear climate trends (1987-2005)

<i>Dependent variable</i>	<i>National average of annual average temperature</i>	<i>National average of total annual precipitation</i>
Model	i (OLS)	ii (OLS)
Linear trend	0.0508 (18.89)***	0.4124 (1.15)
Constant	13.5745 (443.02)***	890.8457 (218.48)***
Observations	494	494
R-squared	0.4203	0.0027
Number of Provinces	26	26

* significant at 10%-level; ** significant at 5%-level; *** significant at 1%-level

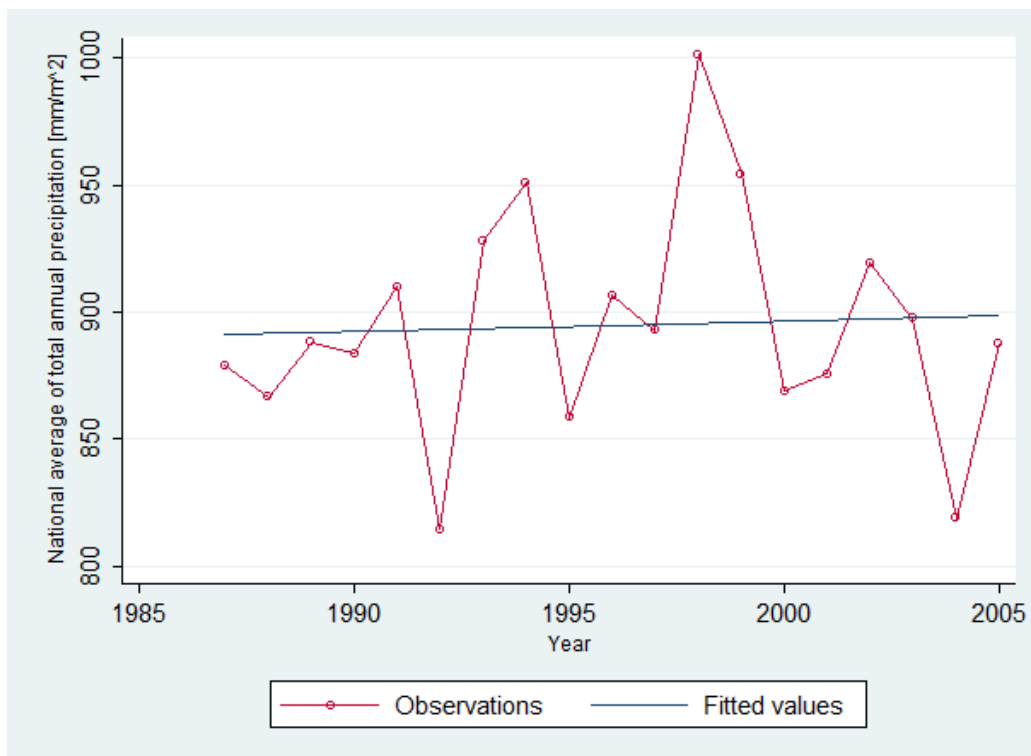
Data: National Bureau of Statistics of China (1988-2006)

Figure 2: Development of China's national average of annual average temperature



Data: National Bureau of Statistics of China (1988-2006)

Figure 3: Development of China's national average of total annual precipitation



Data: National Bureau of Statistics of China (1988-2006)

Table 2: National output and input data of inland fish farming and national average climate observations

Variable	Unit	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Output of fish farms	Tons	10,668,650	11,865,883	12,674,920	13,643,148	14,568,222	15,299,151	16,245,477	17,004,356	18,176,798	19,306,090
Area under aquaculture	Area (1000 ha)	4,772.73	4,813.95	4,799.07	5,049.91	5,127.21	5,194.04	5,304.79	5,403.75	5,497.63	5,683.06
Amount of fry stocked	Number (100 million)	4,028.12	5,113.62	5,814.37	5,919.76	5,784.81	6,185.53	6,686.76	7,029.00	7,055.00	7,863.00
Number of laborers employed	Number	2,544,980	.	2,682,358	2,805,112	2,923,218	3,032,591	3,727,236	3,379,346	3,495,952	3,502,032
Number of boats used	Number	50,615.37	55,190.64	55,923.85	58,575.17	57,943.77	59,180.27	59,180.27	70,594.49	69,461.35	74,248.57
National average of annual average temperature	°C	13.66	14.34	15.01	14.37	14.09	14.38	14.59	14.27	14.59	14.09
National average of total annual precipitation	mm/m ²	906.71	892.76	1001.50	954.31	869.07	875.62	919.64	897.68	818.98	887.74

Data: Chinese Ministry of Agriculture (1997-2006 a&b); National Bureau of Statistics of China (1997-2006)

Table 3: Analysis of Chinese Aquaculture Production

<i>Model</i>	<i>I</i>	<i>II</i>	<i>III</i>	<i>IV a</i>	<i>IV b</i>	<i>V a</i>	<i>V b</i>
	Production Function	Production Function	Production Function	J-P Method (no dummies)		J-P Method (incl. dummies)	
	(FE)	(FGLS)	(FGLS)	Mean Function (NLS)	Risk Function (FE)	Mean Function (NLS)	Risk Function (FE)
<i>Dependent Variable</i>	<i>ln (fish output)</i>	<i>ln (fish output)</i>	<i>ln (fish output)</i>	<i>adj. fish output</i>	<i>output risk</i>	<i>adj. fish output</i>	<i>output risk</i>
Area	0.1610 (5.27)***	0.4704 (10.11)***	0.6367 (13.84)***	0.4725 (14.87)***	-0.4260 (-1.57)	0.6645 (11.06)***	-0.3439 (-0.82)
Fry (one-year lag)	0.0212 (1.39)	0.1279 (6.58)***	0.0835 (4.17)***	0.1799 (25.21)***	-0.4831 (-3.49)***	0.0618 (3.51)***	0.0542 (0.25)
Labor	-0.0355 (-1.75)*	0.2948 (8.86)***	0.1654 (5.4)***	0.1262 (6.43)***	0.4058 (2.14)**	0.1523 (3.56)***	0.7012 (2.39)**
Boats	0.0019 (0.13)	0.0922 (5.11)***	0.0926 (6.39)***	0.0778 (10.72)***	0.3491 (2.32)**	0.0122 (0.65)	-0.1144 (-0.49)
Average temperature			0.7317 (7.99)***	0.5836 (8.18)***	0.0225 (0.02)	1.1081 (8.17)***	-4.3058 (-2.19)**
Total precipitation			0.0425 (1.22)	0.0214 (0.95)	-0.1670 (-0.7)	-0.0111 (-0.51)	0.3248 (0.88)
Temperature deviation			-0.0303 (-1.71)*	-0.0446 (-2.02)**	-0.0605 (-0.47)	-0.0659 (-3.5)***	0.6117 (3.07)***
Precipitation deviation			0.0014 (0.05)	-0.0426 (-2.17)**	0.0228 (0.12)	-0.0090 (-0.49)	0.0925 (0.31)
Trend	0.0563 (21.00)***	0.0313 (6.87)***	0.0373 (6.67)***	0.0287 (9.97)***	0.0090 (0.32)	0.0461 (10.28)***	0.0112 (0.26)
Constant	11.7394 (43.15)***	5.8648 (24.12)***	4.4216 (16.59)***	6.4302 (26.84)***	9.3185 (2.16)**	4.4205 (9.69)***	11.1960 (1.68)*
Observations	192	192	160	160	160	160	160
R-squared	0.8185			0.9966	0.1771	0.9974	0.1395
Number of Provinces	24	24	24	24	24	24	24

* significant at 10%-level; ** significant at 5%-level; *** significant at 1%-level

Data: Chinese Ministry of Agriculture (1997-2006 a&b); National Bureau of Statistics of China (1997-2006)

Notes on Table 3

Absolute value of t statistics in parentheses: Models I, IV-V

Absolute value of z statistics in parentheses: Models II-III

Logarithmic independent variables: Models I-III, IVb, Vb

Non-logarithmic independent variables: Models IVa, Va