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Impact of the adoption of BMPs on social welfare: A case study of commercial floating feeds for pond culture of tilapia in Ghana

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Abstract: Best management practices (BMPs) are the most cost-effective means of mitigating negative impacts of pond aquaculture on the environment. The impacts of BMPs and other innovations on fish farm profits have been studied widely. This study estimates impacts of BMP adoption on social welfare. We employed the economic surplus model to determine net present value (NPV) of adopting the more expensive but less polluting commercial floating fish feed in the pond culture of Nile tilapia (*Oreochromis niloticus*) in Ghana. We also conducted a sensitivity analysis to determine which variables had the greatest influence on mean NPV. Our results indicate an NPV of US$ 11 million from the adoption of commercial floating feed in pond farming alone in Ghana. The variables with the biggest impacts on NPV were level of change in tilapia yield, and level of change in production costs, with the adoption of the new feed type. We conclude that adoption of yield-enhancing BMPs and innovations in Ghana will result in significant social welfare benefits. We recommend that credit programs and other financial packages be set up by governments or nongovernmental organizations to help farmers meet the increased cost of fish feed and to accelerate diffusion of commercial fish feed in pond farming.

ABOUT THE AUTHORS

Yaw B. Ansah received a PhD from the Department of Fish and Wildlife Conservation, and an MSc from the Department of Agricultural and Applied Economics at Virginia Polytechnic Institute and State University (Virginia Tech), USA. His research focus is assessing the impacts of aquaculture BMPs at various levels: farm profitability, social welfare, and environmental sustainability (e.g. pollution reduction) from aquaculture.

Emmanuel A. Frimpong is an associate professor at Virginia Tech, USA. He studies fish biology and aquaculture. He is PI of aquaculture development research in sub-Saharan Africa funded by the USAID AquaFish Innovation Lab. He supervised YBA's dissertation under the project "enhancing profitability of pond aquaculture in Ghana, Kenya, and Tanzania through improved natural resource management and environmental best management practices" out of which the current manuscript was created.

Emmanuel A. Frimpong

PUBLIC INTEREST STATEMENT

The aquaculture industry has the potential to provide much needed low-cost protein, employment, and other socioeconomic benefits, in addition to reducing the pressure on wild fish stocks. Fish farming is therefore being actively promoted in sub-Saharan Africa. However, most forms of aquaculture result in environmental impacts, such as the pollution of rivers from pond effluents. Environmental best management practices (BMPs) are the most feasible means to reduce the negative impacts of fish farming on the environment due to the relatively dilute nature of fish ponds that defy conventional waste treatment. This study estimates the economic benefits to a developing country (Ghana) from the adoption of an aquaculture BMP that simultaneously solves an environmental impact and economic profitability problem. Our results will inform the local ministries and the international development community to design economic and environmental policies specific to agriculture in general and aquaculture in particular.

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1. Introduction

1.1. Background

The World Food Summit was hosted by the UN's Food and Agriculture Organization (FAO) in 1996 to discuss ways to end hunger. The summit resulted in the Rome Declaration on World Food Security (1996). By this declaration, member countries reaffirmed "the right of everyone to have access to safe and nutritious food, consistent with the right to adequate food and the fundamental right of everyone to be free from hunger" (Food and Agriculture Organization, 1996). Fish is recognized as an inexpensive and effective source of protein (Dey, Alam, & Paraguas, 2011). This importance of fish, coupled with declining production from wild fisheries stocks (Subasinghe, Soto, & Jia, 2009), has led to efforts by development agencies to encourage fish farming worldwide. Aquaculture, especially of tilapias, has the potential to play a leading role in the fight against food insecurity, malnutrition, and poverty in Africa (Béné & Heck, 2005).

The global potential for capture fisheries has been reached, due to sustained declines in marine fisheries stocks (Food and Agriculture Organization, 2014). Global demand for fish and fish products, however, continues to increase. Aquaculture has shown great potential towards meeting this growing deficit. Compared to 1980, when production of aquaculture represented only about 5% of global fisheries production, nearly 52.5 million tons of fish and shellfish were produced by aquaculture in 2012, representing almost 50% of global food fish production (Food and Agriculture Organization, 2014). However, while the share of global aquaculture production from most regions of the world has remained the same, the share from sub-Saharan Africa, though low, quadrupled from 0.17% in 2000 to 0.68% in 2012 (Food and Agriculture Organization, 2014). Considering the abundance of water and land, and the increasing population and per capita consumption of fish and fish products in this region, sub-Saharan Africa has a huge potential and need to dramatically increase its aquaculture production.

Classified by the (World Bank, 2014) as a "lower middle income" country, Ghana has an economy largely dependent on agriculture. The agricultural sector contributes 23% of the country's gross domestic product (GDP) annually, whereas 42% of the population was employed in the agricultural sector in 2013 (World Bank, 2014). Ghana's 2.3% annual population growth rate (World Bank, 2014) requires a sustained increase in food production. The country has increased food production per capita by more than 80% since the early 1980s, and is largely self-sufficient in staple crops such as maize, cassava, plantain, and yam (Overseas Development Institute, 2011). The Overseas Development Institute (2011) forecasts that Ghana will meet the United Nation (UN)'s Millennium Development Goal (MDG) 1 of eradicating extreme poverty and hunger by 2015. However, it is important to go beyond meeting this goal of "food quantity" to target "food quality", both of which are components of food security (Food and Agriculture Organization, 1996).

Ghana is one of the countries in the sub-Saharan Africa region with the potential to dramatically increase its fish production through aquaculture. This is the result of a high fish demand, and the combination of a stable political environment and its commissioning of the only commercial fish feed mill in West Africa (Ainoo-Ansah, 2013; Frimpong et al., 2014). The country derives a majority of its dietary protein from fish (Brashares et al., 2004), with an estimated per capita fish consumption of 20–30 kg per annum in 2009 (Food and Agriculture Organization, 2012). This is higher than the global estimate of about 18 kg (Food and Agriculture Organization, 2012).

However, the global aquaculture industry has been blamed widely for its negative impacts on natural aquatic ecosystems (Burridge, Weis, Cabello, Pizarro, & Bostick, 2010; Klinger & Naylor, 2012). There have been several studies on the negative impacts of fish farming. These include: escapes of both genetically altered and unaltered farmed fish into the wild with both ecological and genetic consequences; chemical pollution from pesticides and prescribed drugs, antifoulants, anesthetics, and disinfectants; and eutrophication from nitrogenous and phosphoric compounds in fish feed and pond fertilizer (Ansah, Frimpong, & Amisah, 2013; Burridge et al., 2010; Klinger & Naylor, 2012). Therefore, it is imperative that adoption of innovations to mitigate these negative impacts be encouraged as aquaculture production is increased to meet social and economic goals.

This is because pond effluents are relatively dilute, and as such not amenable to conventional treatment technologies. Aquaculture management practices affect the volume of water, nutrient, solids, and oxygen demand loading rates from ponds to effluent-receiving water bodies (Louisiana State University AgCenter, 2003; Tucker, Kingsbury, Pole, & Wax, 1996). Generally, these practices are grouped into nutrient management and effluent management. Frimpong et al. (2014) showed the effect of two best management practices (BMPs) on the growth of Nile tilapia (*Oreochromis niloticus*) and their effectiveness at preventing the transport of nutrients and solids from fish ponds to water bodies in Ghana. Specifically, these two BMPs were the use of commercial floating feeds and pond water reuse. That study showed that reused pond water resulted in the same growth rates as the usual practice of draining and refilling pond with new water before stocking. This result was in contrast to the widely held belief among pond fish farmers in the sub-Saharan Africa region that reusing water from a previous cycle could harm cultured fish.

Two main types of fish feed are used by fish farmers in Ghana. The recommended commercial feed type is pelleted, smooth, and mostly floating, unlike the farm-made type, which is coarse, powdery, and sinking (Awity, 2013). Frimpong et al. (2014) showed that the commercial floating feed type resulted in up to a 100% increase in fish growth compared to the farm-made sinking feed. Analysis of revenues and costs on a typical tilapia farm in Ghana also indicated that using commercial floating feed resulted in a higher probability of profitability (45%) than using the farm-made alternative (25%) (Ansah, 2014).

Demonstrating profitability of better management practices will encourage their adoption by fish farmers, which will both protect the environment and further increase farm profits. Widespread adoption of profitable innovations is expected to have an impact not only at the farm–household level, but also the welfare of the society as a whole, including both producers and consumers. Positive outcomes of adopting BMPs such as commercial floating feeds include achievement of an "environmentally-friendly" image by the aquaculture industry, increased tilapia production, and lower fish costs (Ansah et al., 2013; Klinger & Naylor, 2012). This study sought to quantify the economic impact of the adoption of floating feeds in pond culture of tilapia in a developing country on social welfare. Specifically, we were interested in the net present value (NPV) of BMP adoption, with Ghana as a case country. Also, it was of interest to determine factors that had the greatest influence on NPV from adoption of the BMP.

1.2. Economic-Surplus model

Generally, according to economic theory, an innovation (a new technology) shifts the supply function for a commodity downwards, resulting in a larger equilibrium quantity at a lower price (Masters, Coulibaly, Sanogo, Sidibé, & Williams, 1996). This development may have a significant bearing on the level of poverty or welfare of a particular community where a new agricultural technology is diffused. The conventional framework for applied welfare economics is provided by a three-part assumption (Harberger, 1971): the demander's perceived value of a unit of a good or service is indicated by the competitive demand price of that unit; the supplier's perceived value of a unit of a good or service is indicated by the competitive supply price of that unit; and the net benefits and costs of a given action to a group of people is the total of the benefits and costs to each member.

We employed the economic surplus method which is the most common method for analyzing the welfare impacts of agricultural research in a partial equilibrium framework according to Alston, Norton, Pardey, & International Service for National Agricultural Research (1998) and Masters et al. (1996). The popularity of this method stems from the fact that it requires the least data, can be applied to the broadest ranges of situations, is easy to grasp, and can be used both *ex ante* and *ex post* (Alston et al., 1998; Masters et al., 1996).

The economic surplus approach uses the concepts of *supply*, *demand,* and *equilibrium* to turn agronomic data into economic values*.* While *supply* represents producers' production costs, *demand* represents consumption by consumers. These two forces interact to produce the so-called *equilibrium* quantity and price. Economic welfare depends on the equilibrium price and quantity and also on the producers' production costs and consumers' consumption values. Equilibrium price and quantity may be observed directly in the market, but the production costs of producers and the consumption values of consumers must be imputed from their actions (Masters et al., 1996).

Economic surplus is the monetary value of production and consumption—the money value that consumers would have paid for each consumed unit, less the monetary value that producers would have paid for each produced unit, up to the actual market price and quantity (Masters et al., 1996). Generally, the economic surplus approximates the social value of a given production and consumption level. This is the area bounded by the supply and demand curves and the equilibrium quantity. The difference between the situation with or without a new technology can be evaluated with the economic surplus model, as a single measure (Alston et al., 1998). Any change in economic surplus with the adoption of a new technology is a measure of the social benefits derived from that innovation. Therefore, using the economic surplus method, the impact of the innovation on social welfare can be determined *ex ante*.

The most essential determinant of the impact assessment results is the magnitude in the shift of the supply curve with the new technology (Masters et al., 1996). This magnitude is measured in terms of money per unit of output. For a given cost of inputs, increased production is represented by a horizontal shift of the supply curve. However, the adoption of an innovation may require some investment in new inputs. For a given level of output, this increased cost is referred to as *adoption costs*, and it represents a vertical shift in the supply curve. In order to obtain a net shift in terms of costs per unit of output, it is necessary to pool data on both changing quantities and changing input costs.

2. Methods and data analysis

2.1. Model

Using the economic surplus model, we estimated the potential benefits of switching from farm-made sinking fish feed to commercial floating feed in pond-based tilapia farming in Ghana. The economic surplus model has been used to study the benefits of a number of new technologies in different countries, e.g. marker-assisted rice breeding in southeast Asia (Alpuerto, Norton, Alwang, & Ismail, 2009), and cassava breeding in sub-Saharan Africa (Rudi, Norton, Alwang, & Asumugha, 2010). The economic surplus model is laid out as follows, according to Alston et al. (1998) and Masters et al. (1996). The total economic benefit from the adoption of a new technology for a non-traded commodity (or commodity from a "small-country producer") is estimated by the formula:

$$\Delta TS = PQK \left(1 + 0.5\, Zn\right) \tag{1}$$

where P and **Q** are the initial equilibrium price and quantity, respectively; **Z** = Ke/(e + n) is the relative reduction in price due to the supply shift resulting from the new technology; **e** is the supply elasticity, and **n** is the demand elasticity (absolute value), which reflect how responsive the quantity supplied and quantity demanded are to change in prices, respectively; and **K** is the shift in the supply curve as a proportion of the initial price. **K** is calculated as:

$$K = \left(\frac{E(Y)}{\varepsilon} \right) - \left(\frac{E(C)}{1 + E(Y)} \right) p\, A\, (1 - d) \tag{2}$$

where **E(Y)** is the expected proportional yield increase per hectare after the adoption of the new technology; **E(C)** is the expected proportional change in variable input cost per hectare; **p** is the probability of success associated with the technology or innovation; **A** is the adoption rate for the technology; and **d** is the depreciation rate of the new technology (Alston et al., 1998). The rate of depreciation of an innovation indicates the reduction in its value from the impact of the development of superior technologies and the decline in its "appropriability" with diffusion and time (Park, Shin, & Park, 2006).

"Economic benefits" is the change in total economic surplus for each year, and the costs are the expenditures on the research plus estimated after project costs related to developing and disseminating the new innovation. The annual costs and benefits are netted and totaled using the social discount rate (SDR) to calculate a NPV using the standard NPV formula:

$$NPV = \sum_{t=1}^{T} \frac{R_t - C_t}{(1 + i)^t} \tag{3}$$

where R_t is the benefits in year **t**; C_t is the research, development, and dissemination cost in year **t**; and **i** is the discount rate. In other words, the NPV is calculated as the sum of future benefits, minus the costs associated with the project discounted overtime.

2.2. Data and key assumptions
To effectively run the economic surplus model, both physical and market data must be collected on the following: (1) the proportion of farmers who adopt the innovation overtime; (2) the price of the commodity; (3) the change in yield of the commodity with the new technology; (4) the nature of the market, as products that are traded may not experience price declines if production increases (Alston et al., 1998; Dey, 2000); (5) the time it takes to develop the innovation, and the number of years for maximum adoption to be reached; and (6) the discount rate for future benefits compared to current benefits.

We raised Nile tilapia (*O. niloticus*) on five demonstration earthen-pond farms in central Ghana. Stocking, feeding, and other management practices employed for the production of tilapia on these demonstrations were consistent with those used on typical tilapia farms in Ghana. These demonstrations provided both physical data on the effects of two BMPs on the growth of Nile tilapia (see Frimpong et al., 2014) and budgeting data for profitability analysis. The two BMPs were use of commercial floating feed (as opposed to farm-made feed prepared on site from food and agro-industrial wastes), and reused water (as opposed to draining and refiling ponds with new water before each production cycle). Frimpong et al. (2014) concluded that of the two BMPs, only feed type significantly influenced fish growth and yield. Using floating feed resulted in average yields 100% higher than using sinking feed. Since there was no significant difference in fish growth with water type (reused or fresh water), we analyzed only the welfare impacts of the adoption of floating feed as a new technology. Reusing pond water for multiple production cycles is clearly environmentally beneficial. However, we did not detect any significant differences in fish yields or farm costs from this BMP. The quantification of the environmental impacts of reusing pond water is the subject of a separate study (Ansah, 2014). Without resulting in differences in growth, the only potential source of economic benefits of water reuse is saving input cost from refilling emptied ponds. The vast majority of pond farmers in Ghana obtain water at no direct cost from diverted streams or groundwater seepage. Cost savings to the farmer are therefore not readily apparent.

The unit cost of the recommended feed type is almost eight times that of the farm-made alternative, and the cost of fish feed makes up over 50% of total costs on a typical fish farm (De Silva & Anderson, 1995). The implication is that the adoption of the new feed technology will result in a 350% increase in total annual farm costs.

The rate of adoption of each BMP was tracked over three years though a comprehensive survey that was administered from 2011 to 2013, to 363 fish farmers in Ghana. Respondents came from the central and southwestern parts of Ghana, specifically in the Ashanti, Brong-Ahafo, Central, Eastern, and Western Regions. Pond farms in Ghana are located mostly within these regions, due to conducive biophysical factors (Kapetsky et al., 1991). Average adoption rates over this period were 58.2% for commercial floating feed and 27.4% for pond water reuse (Ansah, 2014). It is worth noting that most farmers who claim to use the former technology presently do not use it exclusively, but the trial of the technology is an indication of their desire to fully adopt it if it proves superior and affordable (Awity, 2013). We assumed 70% as the maximum adoption rate, which is a realistic figure for an aquaculture innovation (e.g. Dey, 2000).

Aquaculture production in Ghana occurs in two main systems—floating cages in the Volta Lake and dugout earthen ponds. Floating cage systems are intensive operations that rely solely on commercial floating feed through the production cycle, and these systems account for about 90% of the country's aquaculture production (Ainoo-Ansah, 2013, Awity, 2013). Total production from cages alone was 24,250 metric tons (mt) in 2013. Current BMP dissemination efforts are targeted at the less-intensive earthen-pond systems that rely more on the farm-made sinking feed type. Effectively, the adoption of the new feed technology will likely impact the production from earthen ponds, since the innovation is already being used in the cage systems. Analysis of data from Ainoo-Ansah (2013), Awity (2013), and Food and Agriculture Organization (2013) allowed separation of the estimated Nile tilapia production from the total aquaculture production for 2013 in Ghana to be 1,500 mt. We calculated the price per ton of production as $2,646 by dividing FAO's 2011 estimate of the value of tilapia production ($48,159,000) by the annual production that year (18,200 mt, Food and Agriculture Organization, 2013).

A supply elasticity of 0.5 usually is applied to economics of production of perennial crops and other livestock, and demand elasticity of 1 can be used for most livestock production (Alston et al., 1998). Since the floating feed technology exists already, the probability of success of research was assumed to be 100%. Analysis of our demonstration farm data indicated that feed conversion ratios (FCRs) and costs (by extension) in our demonstration ponds and in Ghana were higher than optimum for tilapia culture (Frimpong et al., 2014). A possible way to reduce FCRs and costs is to reduce the crude protein content in the feed to 25% and to reduce the amount of feed used for production. There is, therefore, the need for continuous studies in order to improve and optimize the use of the technology. To achieve this goal, we estimated average annual research and development (R&D) costs at $30,000 (plus sensitivity analysis). Also, an effective and sustained dissemination campaign needs to be organized, to enable a rapid diffusion of the commercial floating feed technology.

Survey respondents were asked to rank which dissemination method was the most influential in their adoption of either BMP. For both BMPs, mean rankings indicated that the most effective method was workshops (central media), followed by demonstration farms, and farmer-to-farmer (personal) dissemination in that order. These were the three dissemination methods that AquaFish CRSP used to diffuse BMPs in Ghana as part of this project. On average, annual expenditure to organize a workshop was US$ 25,000, so we included this as the average annual recurrent dissemination cost for this analysis. We also assumed that the dissemination campaign will be sustained throughout the simulation period, commencing in 2014, to both accelerate and maintain adoption. With this sustained effort to promote diffusion, we assumed 10 years (from 2014) for the maximum adoption rate to be reached. Hence, total annual recurrent costs for R&D and dissemination were estimated at US$ 55,000.

Historically, different values of the SDR have been given in the literature to represent the most appropriate present value of future investments (e.g. Lind,1990). For the NPV analysis, we used an average discount rate of 5% (according to Moore, Boardman, & Vining, 2013), with a range of 2.5–10% in the sensitivity analysis. This range captures most of the figures quoted for the SDR in the literature (e.g. Caplin & Leahy, 2000; Moore et al., 2013).

2.3. Analysis

We included the data and assumptions above in an Excel spreadsheet that incorporates all the model formulas obtained from George Norton at Virginia Polytechnic Institute and State University. We added a possible minimum and a possible maximum value to the average values based on the information in the preceding section to create a triangular distribution for each variable. In order to incorporate uncertainty, distributions were constructed to include the likely full range of variables (Table 1). We ran the model to calculate the NPVs of the annual economic benefits of the commercial floating feed technology for 20 years in Microsoft Excel. The total NPV then was calculated as the sum of these annual benefits. We then conducted economic risk analysis by running Monte Carlo simulations using the @Risk 6 software (Palisade Corporation, Ithaca-NY, USA) for 5,000 iterations. We also conducted sensitivity analysis to determine the influence of key variables (Table 1) on the average NPV.

3. Results

The estimated average NPV of adopting commercial floating tilapia feed for tilapia farming in earthen ponds in Ghana over 20 years was almost US$ 11 million (Figure 1). The probability that the NPV is a positive value was about 70% (Figure 2). Additionally, there was a probability of about 48% that the NPV is greater than the estimated mean value of 11 million (Figure 2). Sensitivity analysis showed that the variables (and direction of correlation) with the greatest impacts on mean NPV were the change in yield of tilapia (+) and the change in production costs (−), resulting from the adoption of

| Table 1. Triangular distributions of key variables used in the Monte Carlo simulation to estimate NPV of adopting commercial floating fish feed in Ghana			
Variable	**Minimum**	**Most likely**	**Maximum**
Recurrent costs ($)	40,000	55,000	70,000
Increase in production costs (%)	150	350	500
2013 Nile tilapia pond production (metric tons)	1,000	1,500	2,000
Peak adoption rate (%)	60	70	80
Yield change (%)	50	100	150
Discount rate	2.5	5	10

Figure 1. Summary of results of Monte Carlo simulation to determine NPV in US$ for adopting commercial floating fish feed in Ghana, showing a 90% confidence interval.
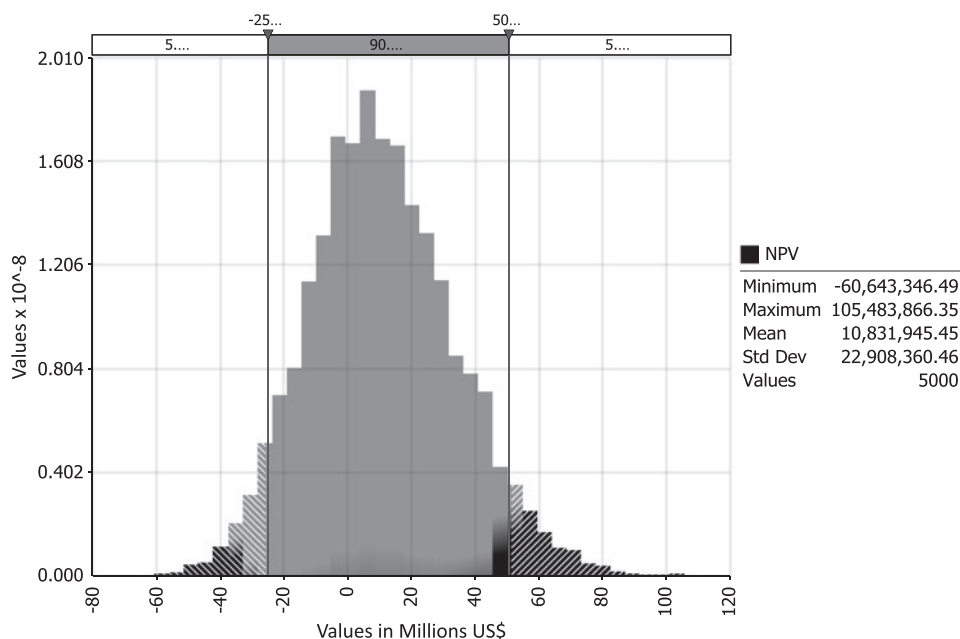
Figure 2. NPVs at different percentiles for adopting commercial floating fish feed in Ghana.
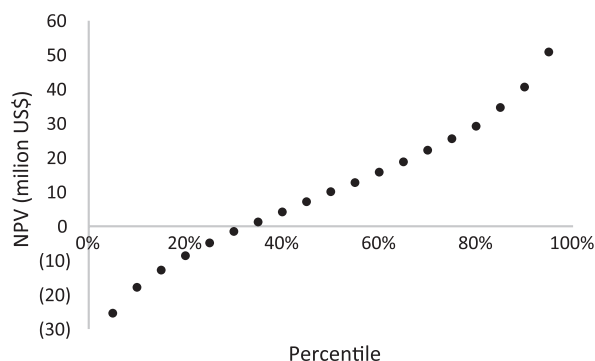
commercial floating fish feed (Figure 3). To a less significant extent, mean NPV also was sensitive to the 2013 tilapia earthen-pond production level (+), the chosen discount rate (−), the level of peak adoption rate (+), and the specific amount of recurrent costs (+), in that order. A plus sign indicates that an increase in that variable will increase NPV, while a decrease in a variable with a minus sign will increase NPV.

4. Discussion

From the results, it emerges that that Ghana's economy has a high probability of profiting significantly from adoption of BMPs, such as use of floating fish feed in earthen-pond farms. The GDP for the country in 2013 was US$ 48 billion (World Bank, 2014). Ghana's agriculture sector contributes about 22% of the country's GDP. This implies that an average NPV of $11 million represents a social benefit of > 0.02% of the country's GDP and > 1% of the portion of GDP contributed by the agricultural sector.

Extrapolations based on figures from Ghana's National Aquaculture Development Plan (Ghana Fisheries Commission, 2012) indicate that the current value of commercially farmed fish in the country to be approximately $40 million (Ansah, Frimpong, & Hallerman, 2014). This implies that our calculated average benefit (US$ 11 million over 20 years) will annually add > 25% of the current value of commercially farmed fish. Clearly, Ghana stands to benefit substantially from the increased fish yield, which will result from adoption of the recommended, floating fish feed. Ansah et al. (2014) identified possible key socioeconomic benefits or impacts of higher fish yields, to include increased employment within the improved aquaculture industry, higher incomes, reduced poverty, possible foreign exchange, lower fish cost, better nutritional diet (more protein), improved health and welfare. Additionally, women in Ghana's fisheries sector are involved more in processing and marketing of fish, and as such, they too will benefit from the increased fish yields from the adoption of the recommended feed type.

The two most influential determinants of NPV were level of change in yield (+) and level of change in production cost (−), with the new feed type. Ansah et al. (2014) conducted a similar analysis, which concluded that Ghana stands to make an NPV of about $375 million from the adoption of

Figure 3. Relative impacts of key variables on the mean NPV for adopting commercial floating fish feed in Ghana across the range of key variables.
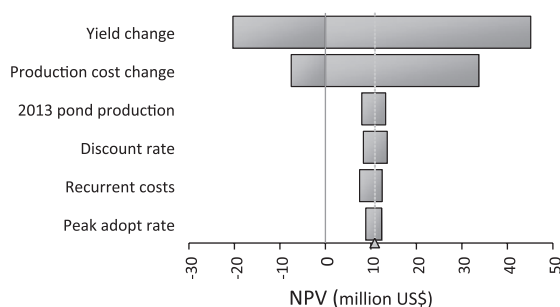
genetically improved farmed tilapia strains in Ghana. That figure is > 300% higher than the calculated NPV in this study for adopting commercial floating feed. Both studies found the change in yield as the most influential variable determining mean NPV. However, although this study considered the welfare impacts of an innovation in the significantly smaller, earthen-pond subsystem, Ansah et al. (2014) calculated the welfare impacts of an innovation that can be used by the bigger pool of tilapia farmers from both production subsystems. This result from the two studies also indicates that any BMP or innovation that significantly increases fish yield also will considerably increase mean NPV and social welfare.

The recommended commercial floating feed type is known to cost almost eight times as much as the alternative feed type produced on farms from a mixture of byproducts of local agro-food industry. It is also not unusual for the cost of fish feed to make up > 50% of variable or total costs of a fish farm (De Silva & Anderson, 1995; Engle & Neira, 2005; Jamu & Ayinla, 2003). Therefore, it is expected that adoption of the recommended feed type will be accompanied by a substantial investment of capital, and principles of innovation adoption (e.g. Rogers, 2003) predict that the higher cost implications could discourage rapid diffusion of this feed innovation among pond farmers in Ghana. However, considering the significant positive social welfare implications of adopting this feed type in earthen pond farming, both governmental and nongovernmental agencies could invest in reducing feed cost in order to facilitate diffusion. Our results indicate that the marginal benefit from any investments made to reduce feed costs and facilitate farmers' use of the new feed type is high.

The acceptable value of the SDR has been a long-standing debate (e.g. Caplin & Leahy, 2000; Moore et al., 2013). Lately, this debate has been rekindled, especially because of the sensitive nature of current analyses of environmental issues, such as global climate change versus global population growth. The SDR allows effects occurring at different future times to be compared by converting each future dollar amount into equivalent present dollars (Weitzman, 2001). The difficulty in this comparison is compounded by the usual uncertain nature of future events. Besides the arguments of which value of SDR to use in calculations, another controversy is whether to use a constant number for an analysis or to allow this number to change. Our Monte Carlo simulation (sensitivity analysis) allowed us to use a range of discount rates instead of a constant number, and results show that although a lower rate will increase NPV, the SDR was not as influential as yield changes or production cost changes in determining mean NPV of the feed innovation.

The least influential variables determining mean NPV were amount of the recurrent costs of improving and disseminating the relatively new feed type and the level of the peak adoption rate. Whereas our results imply that investing in recurring costs (R&D and dissemination) of the new feed technology will not have a direct increasing effect on mean NPV, awareness of an innovation is well known to be the primary requirement for diffusing that innovation (Rogers, 2003). As such, active dissemination of this BMP to farmers will facilitate its adoption. Only then will the attractive NPV estimated in this study be achieved.

Also, adoption rates of the recommended feed type had a nonsignificant but positive effect on mean NPV. However, adoption rate links indirectly to change in yield. Change in yield is the physical change in the average weight of fish fed the new feed type, but the more farmers that adopt the technology the higher the chances of increasing production in order to realize the calculated NPV.

5. Conclusions

This study projected that adoption of yield-enhancing aquaculture BMPs and innovations in a developing country such as Ghana would result in significant social welfare benefits. Considering the high marginal benefits of investments in floating feed, we recommend that affordable credit programs and other financial packages be created to help farmers meet the current price of fish feed. We also recommend that investment into research and development projects to reduce the amount of feed wasted from overfeeding. The focusing of extension effort on production technologies will lead to

the realization of benefits and reduction in risk. These efforts will result in the country reaping high social benefits from the increased yield. Also, active dissemination of this and other BMPs will create the awareness required for rapid diffusion of these innovations.

Competing interests
The authors declare no competing interests.

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Cover image
Source: Authors.

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