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Evaluating economic costs and benefits of climate resilient livelihood strategies

S. Liu [a,*], J. Connor [b], J.R.A. Butler [c], I.K.D. Jaya [d], A. Nikmatullah [d]

[a] *CSIRO Land and Water Flagship, Black Mountain, Canberra, ACT 2601, Australia*
[b] *CSIRO Land and Water Flagship, Urrbrae, Adelaide, SA 5064, Australia*
[c] *CSIRO Land and Water Flagship, EcoSciences Precinct, GPO Box 2583, Brisbane, QLD 4001, Australia*
[d] *Faculty of Agriculture, University of Mataram, Jl. Majapahit 62, Mataram 83125, Nusa Tenggara Barat Province, Indonesia*

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ABSTRACT

A major challenge for international development is to assist the poorest regions to achieve development targets while taking climate change into account. Such 'climate resilient development' (CRD) must identify and implement adaptation strategies for improving livelihoods while also being cost-effective. While the idea that climate resilience and development goals should be compatible is often discussed, empirical evaluations of the economic impacts of actual CRD investments are practically non-existent. This paper outlines a framework to evaluate economic returns to CRD and applies it in two adaptation strategies trialed in Nusa Tenggara Barat Province, eastern Indonesia. The evaluation framework is composed of three models: a household benefit cost model, a diffusion model, and a regional benefit cost model. The models draw upon the impact evaluation, technology diffusion, and risk assessment literatures, respectively. The analyzes are based on expert opinion and locally-derived information, and hence can be applied in data-poor situations typical of developing countries. Our results explore economic costs and benefits at the household and regional scale, and we identify key input variables that greatly influence the economic returns of the strategies. These variables should therefore be a focus of ongoing investment. We also discuss how the framework is more generally applicable, its limitations including challenges in accounting for less tangible social and ecosystem service benefits, potentially leading to the underestimation of impacts, and how the approach should be complemented by qualitative methods.

Introduction

Many developing countries will be among the most severely impacted by climate change, and failure to act now to mitigate and adapt to climatic risks could lead to greater future costs to lives and livelihoods (Ranger and Garbett-Shiels, 2012). In the context of international development assistance, the key question is not "how can damage from climate change be minimized?" but rather "how can development targets be reached while taking climate change into account?" Joint consideration is critical, not only because climate change can pose risks to meeting development goals, but more importantly, considering climate change presents an opportunity to address development challenges with a fresh perspective (Butler et al., 2014, 2015).

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* Corresponding author. Tel.: +61 2 6246 4803.
E-mail address: shuang.liu@csiro.au (S. Liu).

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'Climate compatible development' aims to minimize risks and maximize opportunities, and requires decision-makers to identify 'triple win' strategies that generate climate adaptation, mitigation and development benefits (Mitchell and Maxwell, 2010). More recently, this approach has been termed 'climate-resilient development' (CRD; (USAID, 2014)). Although empirical evidence of the potential benefits of CRD is gradually accumulating (Economics of Climate, 2009), no attempt has been made to simultaneously evaluate the economic costs, benefits and uncertainties of CRD-based international development assistance projects (Tompkins et al., 2013).

In this paper, we propose an evaluation framework to fill this gap. The framework is composed of a three-stage simulation model developed using a Monte Carlo simulation with benefit cost analysis (BCA) drawing insights from the literature on impact evaluation, technology, and risk assessment. We demonstrate this framework by assessing the economic returns and uncertainties of two CRD strategies developed by a project that aimed to establish adaptation pathways for rural livelihoods in Nusa Tenggara Barat Province (NTB), Indonesia through participatory development and extension approaches. The evaluation framework involves assessing the economic profitability of the strategies and providing suggestions to improve the performance of future investments into them. This is important because international development resources are expected to be stretched to meet growing demands under a changing climate, and cost-effective international development assistance is an issue of increasing urgency (Tompkins et al., 2013). The results of the analysis contribute to the evaluation of the project, which is featured in this special issue (Butler et al., 2016a).

Methods and data

An evaluation framework for climate-resilient development strategies

We developed a framework to evaluate the economic efficiency of CRD interventions targeted at household livelihood strategies. The framework consists of three models: a benefit cost (BC) model at an individual household level, a diffusion model, and a BC model at a regional level. Each model draws upon literature from impact evaluation, technology diffusion and risk assessment, respectively (Fig. 1).

In the first stage, the BC model estimated the benefit of CRD investment at the household level. The benefit is the difference between the net benefit of an innovative farming practice development and extension project and a 'counterfactual', defined in the impact evaluation literature as an estimate of what the consequence would have been in the absence of an intervention (Gertler et al., 2011). Drawing on lessons from the agricultural technology adoption literature, we developed a diffusion model to predict the benefit of investment at a regional level. Finally, guided by literature on risk assessment, we calculated the economic efficiency of the project investment and applied Monte Carlo analysis to present both the range and the expected value of the collective impact of various uncertain factors determining benefits and costs.

Household benefit cost model

Impact evaluation assesses the net effect of a policy intervention by comparing its outcomes with an estimate of what would have happened in the absence of the intervention (Mayne and Stern, 2013). It links cause and effect by assessing the direct and indirect causal contributions of the intervention to change in people's lives (AusAID Office of Development Effectiveness, 2012). Ideally, measures of impact require comparisons of the same ecosystems, individuals, and social groups with and without the intervention at the same point in time. Clearly, such evaluations are not often possible, and evaluators must confront the problem of a missing counterfactual.

In solving this problem, scholars and practitioners have developed different evaluation methodologies, including experimental approaches such as randomized controlled trials (RCTs), quasi-experimental approaches such as instrumental variable (IV), regression discontinuity (RD) and difference-in-difference (DID) (Gertler et al., 2011). The evaluation methods differ in several respects, though they all, in one way or another, try to deal with the problem of missing counterfactuals. That is, they try to assess what would have happened without the intervention by defining a comparison or control group (Lensink, 2014).

Impact evaluation is not a unified practice. Different schools of thought have developed their own approaches and have long debated the merits of one design over another. Yet, most evaluators now support methodological diversity and pluralism (Preskill, 2009; Bell et al., 2011; AusAID Office of Development Effectiveness, 2012), and relying on a single method or technique will be weaker than obtaining multiple perspectives, termed triangulation (Leeuw and Vaessen, 2009).

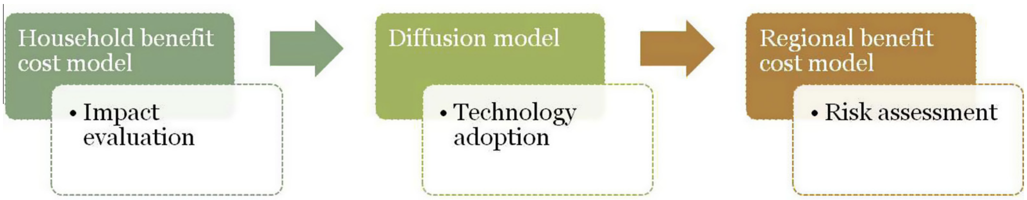

Fig. 1. The evaluation framework for climate-resilient development strategies.

We applied a benefit cost analysis (BCA) with a Theory of Change (ToC) based approach (validation by participants that their actions and experiences are ‘caused’ by the investment; Stern et al., 2012) to evaluate the impact of two CRD investments described below. A strength of BCA is that it provides a single measure of how large the net impact is in terms of economic returns, and a BC ratio can be effectively communicated to decision-makers. However, it has a limited capacity in demonstrating ‘why’ and ‘how’ impacts are generated. The complementary ToC approach provided these perspectives, and is presented separately in this special issue (see Butler et al., 2016b).

In a given year y, the net benefit of the strategy is the difference between the actual developments and the counterfactual (Eq. (1)). The former is what has happened as a result of the CRD strategy at a household level, *net benefit crd hh* (y), and the latter is what might have happened without the strategy, that is, the net benefit of the traditional practice, *net benefit trd hh* (y).

$$Benefit\ per\ hh\ (y) = Net\ benefit\ crd\ hh\ (y) - Net\ benefit\ trd\ hh\ (y) \tag{1}$$

Diffusion model

Adoption and diffusion are the processes governing the utilization of innovations such as the innovative farming practices introduced by the CRD strategy (Sunding and Zilberman, 2001). It is useful to distinguish between adoption, which is measured at one point in time, and diffusion, which is the spread of a new technology across a population over time. Hence, diffusion can be interpreted as aggregated adoption.

Technology adoption may also be viewed from micro and macro perspectives (Feder and Umali, 1993). At the micro level, each decision unit (e.g. a household) must choose whether to adopt the innovation and many adoption studies therefore examine the factors influencing such a decision. At the macro level, after the innovation is already in use, the adoption pattern of all decision units is examined over time to identify the specific trends in the diffusion cycle.

Diffusion studies depict an innovation that penetrates its potential market (Sunding and Zilberman, 2001). Observed diffusion patterns depend critically on complicated and sometimes unobservable relationships between different elements such as the risks associated with various technologies, the nature of farmers’ attitudes to risks, the existence of fixed adoption costs and the availability of cash resources. Similar innovations may therefore experience different adoption patterns in different areas and by different groups of farmers (Feder et al., 1982).

Much of the literature on diffusion assumes that the cumulative proportion of adoption follows an S-shaped curve in which there is slow initial growth in the use of the new technology, followed by a more rapid increase and then a slowing down as the cumulative proportion of adoption approaches its maximum (CIMMYT Economics Program, 1993; The World Bank, 2008). In stage two of our evaluation framework, the number of households that has adopted the farming or fishing practice in a given year y (*# of hh adopted* (y)) is simulated by the logistic model as follows (Eq. (2)):

$$\#of\ hh\ adopted\ (y) = \frac{Max\ hh \times Initial\ \#\ of\ hh\ adopted \times e^{diffusion\ rate\ r \times y}}{Max\ hh + Initial\ \#\ of\ hh\ adopted \times (e^{diffusion\ rate\ r \times y} - 1)} \tag{2}$$

where *max hh* is the maximum number of households that can potentially adopt the innovation, *initial # of hh adopted* is the total number of adopting households before *Year y*, and r is a parameter reflecting the rate of diffusion. The value of r will depend upon such factors as the nature of the specific innovation, economic factors, the social system in which it is introduced, and the channel and change agents used to diffuse it (Feder and Umali, 1993).

When the impacts of a project are expected to be continuous over a number of years, simulation modeling is often applied to integrate existing and new evidence to answer the evaluation questions (UK Government HM Treasury, 2011). We constructed a simulation model and used the S-shaped logistic model to estimate the welfare gain from current and prospective future diffusion of the farming practices to wider populations of potential adopters in NTB. This involved three steps:

(1) Identifying the population of adopters that could possibly take up the new practices (i.e. *max hh*).
(2) Based on agricultural innovation diffusion literature and information elicited from local experts, identifying the parameters of the logistic function, including the diffusion rate, the maximum number of adopters and the life span of the technology.
(3) Assigning values and defining distributions for the parameters, using conservative measures when making any assumptions during the process.

Regional benefit cost model

One limitation of standard BCA is that the values of key parameters of input and output variables are deterministic in nature. However, most inputs, outputs, and impacts of development projects are not known with certainty, and this is especially true for a BCA exercise where benefits are prospective in nature. In our examples, both CRD strategies only started in 2011 but were expected to produce benefits for a decade or more, so the risk-based BCA was critical to evaluate the full range of potential costs and benefits.

In the context of BCA, a risk assessment involves studying the probability that an intervention will achieve a satisfactory performance such as reaching a threshold value of BC ratio or the Net Present Value (NPV); (European Commission Directorate General Regional Policy, 2008). Starting from the deterministic BCA framework, in which ‘best guess’ values of costs and benefits are considered, input variables (the imprecisely quantified factors influencing benefits and costs) become part of a probabilistic model that provides an estimate of the degree of uncertainty affecting the BCA results (Florio, 2014).

Two World Bank studies have introduced risk assessment techniques for BCA (Pouliquen, 1970; Reutlinger, 1970). Instead of varying BCA inputs individually, the possible range of each variable and the likelihood of occurrence of each value within this range is used. Over the years, this ‘probability analysis’, in combination with stochastic simulation models with repeated randomly drawn input values to produce distributions of outcomes, has become the most widely used approach for project appraisal under uncertainty (Anderson, 1989). More recently, this integrated method has been further developed and termed ‘risk analysis’, and Monte Carlo techniques are today a standard tool for analyzing the risk associated with an intervention (Florio, 2014).

A risk analysis entails identifying key variables, performing a sensitivity analysis of those key variables, and prioritizing variables to monitor during implementation (The World Bank, 2010). Using the Monte Carlo method, a full risk analysis to establish an expected NPV or BC ratio of an intervention based on a probability distribution of all the potential outcomes includes the following five steps (Commonwealth of Australia, 2006):

(1) The probability distribution of values for each variable affecting the outcome is specified.
(2) A value for each of these variables is then selected at random.
(3) The NPV or BC ratio implied by the randomly selected values is estimated.
(4) The process of assigning random values to the variables is repeated many times to build up a probability distribution of outcomes.
(5) The process is concluded when further calculations no longer affect the relative frequency of outcomes.

Monte Carlo simulation is a risk modeling technique that uses statistical sampling and probability distributions to simulate the effects of uncertain variables on model outcomes, and the approach provides a systematic assessment of the combined effect of multiple sources of risk in key variables (New Zealand Treasury, 2005). When the number of uncertain variables is too large for a meaningful judgment to be made using sensitivity analysis, Monte Carlo analysis furnishes the decision-maker with a range of possible outcomes and the probabilities of their occurrence for any choice of action.

In this study we used @Risk, a Monte Carlo simulation add-in for Excel (Palisade, 2014) to conduct a full risk analysis. The first step was to define a probability distribution for any uncertain inputs. We elicited the minimum, most likely, and maximum of each variable from local experts and used a triangular distribution for those variables where we had all three values. When the most likely estimate was not available, we used a uniform distribution, where all values (within the range defined by the minimum and the maximum) had an equal chance of occurring. We then ran the risk-based BCA model with 1000 iterations, each time using a different set of random values from the probability functions. The risk analysis produced a probability distribution of possible outcomes. In this way, Monte Carlo simulation provides a more comprehensive view of potential outcomes.

In stage three of the evaluation framework, we developed a BCA model at a regional level, where the net returns of the CRD adaptation strategies (*CRD project net returns*) is calculated by the difference of discounted regional benefit and cost (Eq. (3)).

$$CRD\ project\ net\ returns = \sum_{y=1}^{n} \frac{Benefit\ per\ hh\ (y) \times \#\ of\ hh\ adopted\ (y)}{(1 + Discount\ rate)^{y}} - \sum_{y=1}^{n} \frac{Project\ cost\ (y)}{(1 + Discount\ rate)^{y}} \quad (3)$$

CRD adaptation strategy examples

Background and study area

The strategy examples were derived from a multi-stakeholder planning process carried out in NTB, in 2010–2014 (Butler et al., 2016b). NTB (Fig. 2) is one of the poorest regions within Indonesia, and its largely rural population is highly dependent upon climate-sensitive agriculture and fisheries. The project’s process identified ‘no regrets’ adaptation strategies for rural communities, defined as those which yield benefits under any future conditions of change (Hallegatte, 2009), and therefore potentially deliver CRD (Butler et al., 2016c).

In 2012–2013, 12 adaptation strategies were trialled over 18 months in case study sub-districts (Fig. 2). All but one strategy, land suitability analysis under future climate change, involved action research and training of farmers and other community participants (Table 1). One strategy explicitly aimed to encourage co-management of water resources by upstream and downstream users. However, only two of the strategies (castor-based intercropping and *bondre* seaweed production) were considered to be appropriate for economic evaluation using our framework. For the remaining 10, it was difficult to establish a counterfactual due to the lack of a precedent (e.g. mangrove-based mud crab aquaculture, off-season mangoes), their focus on capacity building (e.g. dissemination of climate change information to farmers, integrated water resource management) or desk-top analyzes (e.g. land suitability analysis under future climate change). For many of these it was also difficult to apply market prices.

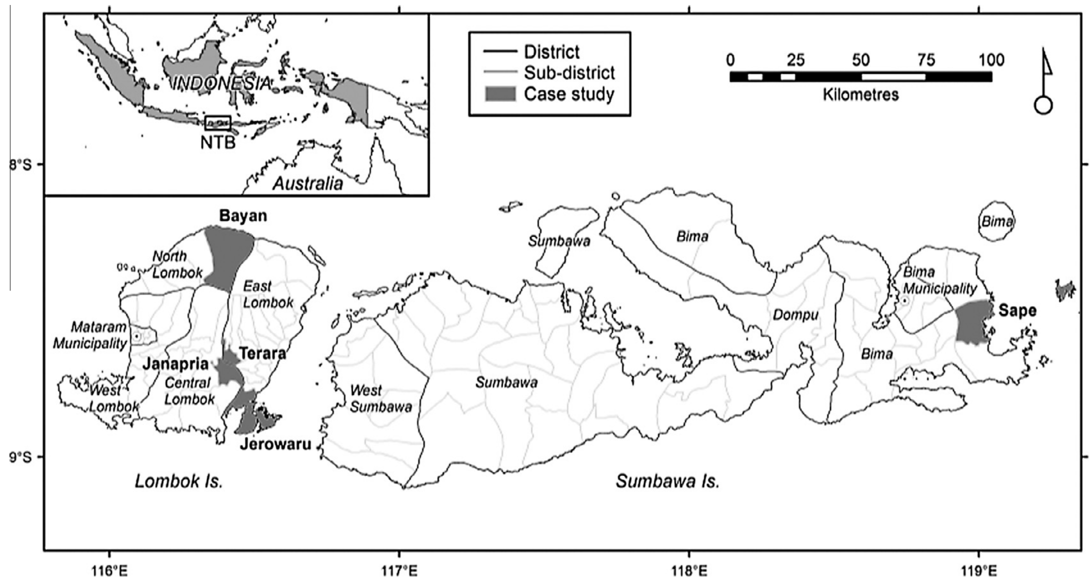

Fig. 2. Nusa Tenggara Barat Province, Indonesia, showing the locations of the case study sub-districts.

Table 1
The 12 adaptation strategies trialed in case study sub-districts of Nusa Tenggara Barat Province, 2012–2013.

Adaptation strategy	Objective	Case study sub-district
1. Dissemination of climate change information to farmers	Understand the climate change information needs of farmers, and introduce local Climate Forums to raise awareness and promote discussion	Terara
2. Integrated water resource management from a gender perspective	Provide technical training on sustainable irrigation management to women and men, promote catchment-scale co-management, and identify non-water dependent alternative livelihoods (e.g. bee-keeping)	Bayan
3. Castor-based intercropping	Introduce intercropping of traditional maize and mung bean crops with castor oil plants to diversify dryland production, promote tolerance to climate variability, and higher yields	Jerowaru
4. Land and water conservation through small-scale agroforestry	Apply biopores using plant residue from agro-forestry to promote dryland soil and water conservation and fertility	Bayan
5. Non-rice foods for food security	Promote cassava growing and processing in villages by women as a substitute for rice	Janapria, Terara, Bayan
6. Organic fertilizer development and application	Develop organic fertilizer production and train farmers to apply it	Bayan
7. Mangrove-based mud crab aquaculture	Test the viability of mud crab rearing in mangroves to provide a high value product and to justify the conservation of mangroves for coastal protection	Jerowaru
8. Integrated crop and livestock systems	Train farmers to integrate multi-cropping and livestock systems within and between farms to diversify livelihoods and increase productivity	Bayan
9. Land suitability analysis under future climate change	Analyze land suitability for rice and maize under projected climate regimes	Sape, Bayan, Terara, Janapria, Jerowaru
10. Livestock as a strategy to promote livelihood resilience	Assess the value of livestock as a livelihood asset which promotes resilience during climate extremes	Jerowaru
11. *Bondre* seaweed production	Develop and test an alternative method of seaweed production which is more resilient to storms than the traditional bamboo raft system	Jerowaru
12. Off-season mangoes	Train mango producers to apply early-ripening hormone treatment 'paclobutrazol' to enable access to higher market prices	Bayan

Castor-based intercropping

Traditional dryland farming in NTB can be challenging. Most maize, mung bean, and chili grown on drylands is produced during the rainy season. At the end of the season the prices of these crops are usually low due to high supply; the productivity of dryland farmers' land is also under jeopardy because of its low organic matter content, coupled with droughts and floods in recent years that are associated with climate variability (Jaya et al., 2012), which is likely to be exacerbated by climate change (Kirono et al., 2016). Without appropriate cropping technology and adaptive varieties, yields of these crops could be under threat and households can benefit from farming system adaptations that increase climate resilience.

Intercropping species such as castor (*Ricinus communis* L.), a bio-energy crop, into maize and mung bean plantings was identified by stakeholders as a potentially innovative solution. Castor plants grow fast and are capable of accumulating significant carbon in their biomass and roots. Therefore, they can improve soil organic carbon and improve land productivity (Jaya et al., 2014). In addition, the plants can also mitigate the impacts of extreme weather by providing a suitable microenvironment for the maize and mung bean they are intercropped with. Apart from the castor intercropping, the trialed farming system also involved improved selection of locally adapted open-pollinated corn and bean cultivars, instead of the predominantly-used hybrid seeds.

For the counterfactual we estimated the net benefit for a typical household that used the traditional dryland farming system, where maize and mung bean are grown side by side simultaneously. The analysis evaluated the net benefit of a typical household that adopted the innovative system. The farmer intercrops castor with a new variety of short-season maize, followed by a new variety of mung bean. Higher yields, decreased production costs, an additional cash crop (castor), and savings from their own seed propagation contribute to increased welfare for individual households switching from the traditional to the new practice. The benefit assessment was probably an underestimate because we were not able to evaluate the non-market impacts of the castor intercropping system (Bennett et al., 2012), such as the ecosystem services of water retention that would reduce water quality impacts and provide climate regulation benefits through increased carbon sequestration.

The net benefit at the household level was the difference in household net benefits derived from the intercropping and traditional practices. We applied the S-shaped logistic model to estimate the welfare gain from current and prospective future diffusion of the castor intercropping system in NTB. We then calculated the NPV of the regional benefit by aggregating household welfare estimates across NTB and over time. The values and distribution of input parameters for the household CBA model, diffusion model, and regional/project CBA model were based on the literature, statistical data, expert opinion and field surveys. Table 2 below shows the range of values and distribution for the key uncertain parameters.

We attempted to be consistently conservative in parameterizing input variables. For example, when estimating the trial cost, we assumed the same amount of resources and time invested in the 18 months of the trial is required in the following years, even though it was likely that less effort would be required over time to maintain the benefits. In addition, we also used a ‘most conservative’ scenario when calculating project BC ratio, whereby we considered only the benefits to households that have already adopted the new farming practice, and the costs already incurred in developing and implementing the trial. This scenario is equivalent to assuming that implementation does not continue and no further households adopt the innovation. We also assumed in this scenario that the adopters will not continue to use the technology after 2014.

We also considered two diffusion scenarios with an assumed longevity of 5 and 10 years. Because the trial started in 2012 (year 1 in our model), essentially we attempted to predict the BC ratios by 2017 (year 5) and 2022 (year 10). Based on local expert opinion, we assumed that potential adopters in the dry land area of NTB ranged from 2000 to 8000 households.

Bondre seaweed production

Traditionally, seaweed in NTB is grown on bamboo rafts in the wet season (Amin et al., 2008). Occasional severe monsoon storms break the rafts, destroying the seaweed culture, causing livelihood loss and costs of rebuilding rafts and restocking with wild-harvested seaweed stock. Regional projections suggest that such storms are likely to increase in intensity with climate change (McGregor et al., 2016).

Under the alternative strategy, seaweed is grown in *bondre* (mesh bags) anchored to the seabed. The system is more resilient to storms. Benefits include reduced loss in severe storms, decreased operational costs of rebuilding and restocking, and a source of transplants that can be sold to traditional seaweed-growing farmers who have lost their production and need to reseed after storms. Additionally, the *bondre* system can provide seedlings for early cultivation in the next cropping season and is useful for restocking the farmers’ own production.

For the counterfactual we estimated the net benefit of a typical seaweed-growing household that uses the traditional raft system. The *bondre* case evaluates the net benefit of a typical seaweed-growing household adopting the innovation. Under the traditional practice, seaweed-growing farmers lose all their production in a storm year, resulting in zero income, while

Table 2
Distributions of uncertain inputs for the castor-based intercropping example.

Variable description	Variable name	Unit	Function form and value range
1. Household benefit cost model			
Probability of production failure due to drought for the castor system	*Prob castor*	%	Uniform, 0–10%
Maize productivity of the castor and traditional systems	*Productivity maize*	kg/ha year	Uniform, 1800–5900
Mung bean productivity of the traditional system	*Productivity trad bean*	kg/ha year	Uniform, 20–300
Mung bean productivity of the castor system	*Productivity cast bean*	kg/ha year	Uniform, 750–1300
Castor productivity	*Productivity castor*	kg/ha year	Uniform, 400–800
Percentage of bean production area of the castor system	*Area cost bean*	%	Triangular (0, 0.5%, 1%)
2. Diffusion model			
Diffusion rate of the castor innovation	*Diffusion rate*	na	Uniform, 1–2
Maximum number of households adopting the castor innovation	*Max hh*	count	Uniform, 2000–8000
3. Regional benefit cost model			
Discount rate	*Discount rate*	%	Triangular, (3%, 7%, 11%)
Life span of the intercropping system	*Y*	year	5 and 10

the *bondre* farmers maintain income. The *bondre* system also has a lower production cost compared to the traditional system, incurring only establishment costs once every 6 years, and it is also cheaper to grow seaweed with the new technology.

Again we maintained consistently conservative estimates during parameterization. Table 3 documents the values and distribution of the key uncertain inputs for Monte Carlo analysis.

As with the intercropping example, we again applied a 'most conservative' scenario when calculating the project BC ratio. Similarly, we considered two diffusion scenarios with an assumed longevity of 5 and 10 years, meaning we attempted to predict the BC ratios of the project by 2017 (year 5) and 2022 (year 10). Based on local expert opinion, we assumed that the range of potential seaweed-growing households in NTB was between 8000 and 32,000.

Results

Castor-based intercropping

Household benefit cost model

At the household level, the NPVs of the benefit of switching from the traditional to the intercropping systems are approximately $1300, $2100 and $3500 (in 2012 AUD, median values, based on 1000 iterations) for the most-conservative, 5-year and 10-year scenarios, respectively. So, for a typical NTB household that adopted the new practice in 2012 and continued to use it, the innovation would result in an NPV of $2100 if the life span of the technology is 5 years and $3500 if the life span is 10 years. On average each household will therefore have a welfare increase of $300–$400 per year. This is similar to NTB's Gross Domestic Product (GDP) per capita in 2011 (i.e. 4.274 million Rp or AU$420; (Regional Economic Development Institute, 2013).

Fig. 3a shows the distribution of the NPV of the household benefit for the most-conservative scenario, based on 1000 iterations. Fig. 3b lists input variables ranked by their effect on output mean. The production area of the new mung bean variety has the most significant effect on the NPV of the household benefit.

Diffusion model

Farmers in NTB started to adopt the technology in 2012, and up to the first quarter of 2014, 71 households in total switched to the new practice. Using the logistic model, we attempted to predict the total number of households that would adopt intercropping under the 5-year and 10-year scenarios.

If the diffusion of the technology continues, our conservative prediction is that there will be 230 households using the technology by 2017 (assuming the new system has a life span of 5 years), and almost 4200 households by 2022 (median values based on 1000 iterations). Both the maximum number of adopters and diffusion rate can greatly influence the total number of households switching to the intercropping system by 2022.

Fig. 4 demonstrates the increase in the predicted number of adopters over 10 years, according to our logistic model as well as the actual number of adopters between 2012 and 2014. Note that for the 2.25 years for which we have data, the predicted numbers are lower because of the conservative assumptions about the diffusion rate.

Regional benefit cost model

Table 4 reports the NPV of regional benefit and cost estimates of three scenarios and their corresponding BC ratios. At the regional level, the NPV of the benefit will reach more than AU$3 million if the life span of the technology is 10 years. On the cost side, the regional NPV will accumulate to about $248,000 from 2012 to 2022. In this case, the BC ratio is around 14.

Table 3
Distributions of uncertain inputs for the *bondre* seaweed production example.

Variable description	Variable name	Unit	Function form and value range
1. Household benefit cost model			
Probability of production failure due to storm	*Prob storm*	%	Triangular, (3%, 7%, 11%)
Number of *bondre* units per household	*Bondre #*	count/hh	Uniform, 10–20
Income of *bondre* systems in non-storm years	*Bnd non-storm*	million RP/(unit cycle)	Uniform, 0.09, 0.12
Income of *bondre* systems in storm years	*Bnd storm*	million RP/(unit cycle)	Uniform, 0.15–0.18
Income cycles of *bondre* in storm years	*Bnd storm cyl*	count	Uniform, 7–8
Income of raft systems in non-storm years	*Rft non-storm*	million RP/(unit cycle)	Uniform, 0.9–1.2
Income cycle of raft in non-storm years	*Rft storm cyl*	count	Uniform, 4, 5
2. Diffusion model			
Diffusion rate of the *bondre* innovation	*Diffusion rate*	na	Uniform, 2–3
Maximum number of households adopting the *bondre* innovation	*Max hh*	count	Uniform, 8000–32,000
3. Regional/project benefit cost model			
Discount rate	*Discount rate*	%	Triangular, (3%, 7%, 11%)
Annual cost of the trial	*Project cost*	$	Uniform, 21,840 – 32,760
Life span of the *bondre* system	*Y*	year	5 and 10

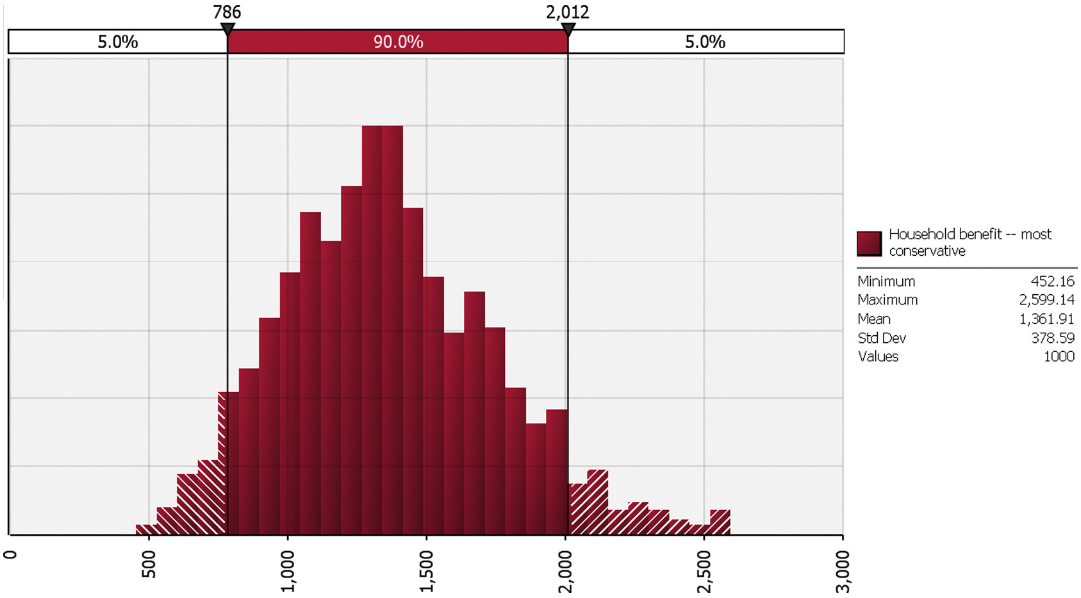

Fig. 3a. Distribution of the NPV (AU$) of the household benefit of switching to the intercropping system, according to the most-conservative scenario (based on 1000 iterations).

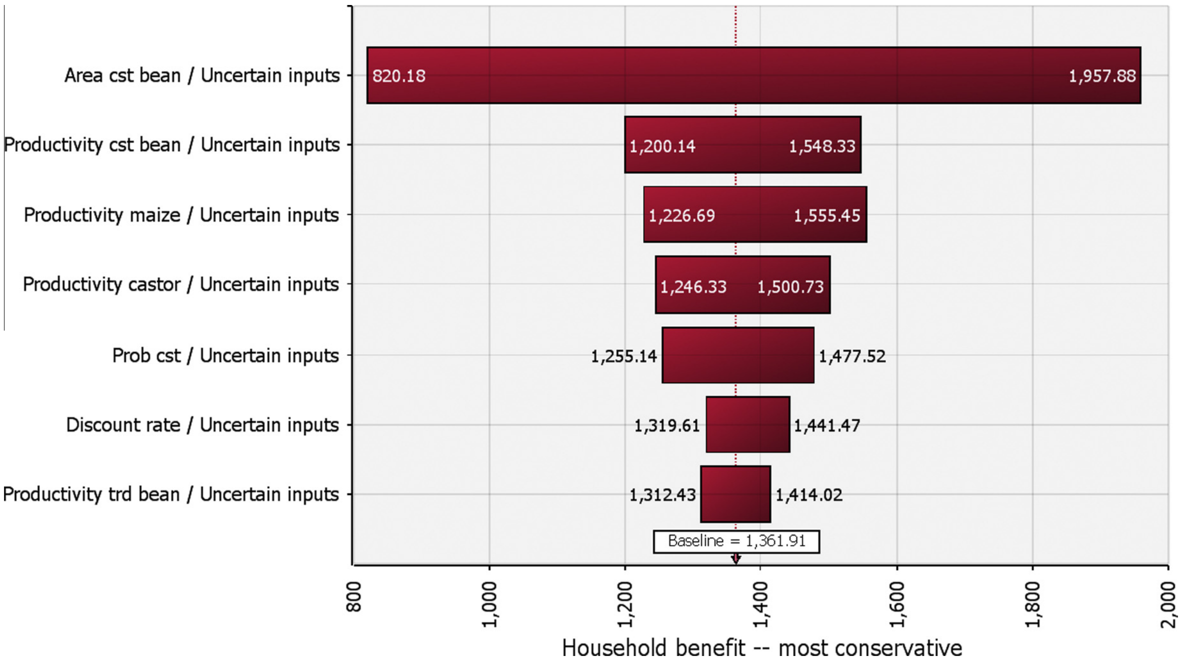

Fig. 3b. Input variables ranked by their effect on the mean NPV of household benefit of switching to the intercropping system.

However, if the life span of the intercropping technology is only 5 years, then the BC ratio of the project is approximately 1. In the latter case the NPVs of both benefit and cost are around $140,000.

In the most-conservative scenario, the trial cost is $84,000, and the benefit for the 71 households that have adopted the technology is about $57,000. Our calculation results in a BC ratio of approximately 0.7 for the trial's investment to date.

Fig. 5a demonstrates the wide range of possible values for the BC ratio for the 5-year scenario. There is a 51.2% chance that the ratio is smaller than 1. By comparison, for the 10-year scenario, we are almost certain that BC ratio is larger than 1 (Fig. 5b).

Among all the uncertain inputs, the diffusion rate, the production area of mung bean and the maximum number of adopters have the largest effects on the BC ratio (Fig. 6). Further analysis shows that these three parameters are all positively correlated with the BC ratio.

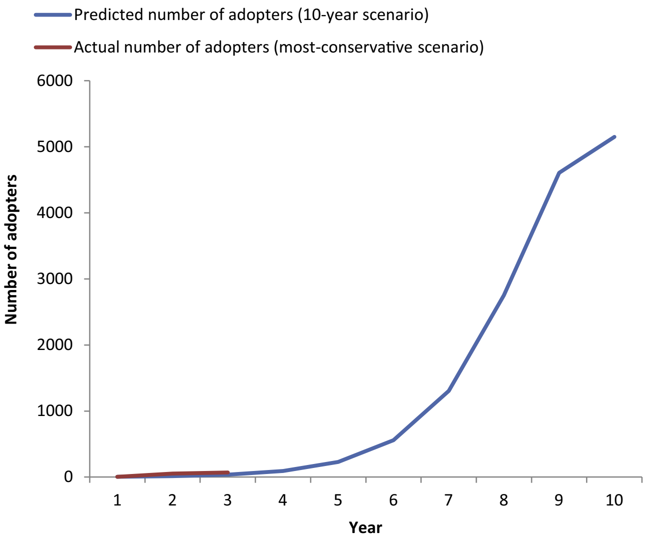

Fig. 4. Predicted and actual number of households that adopt the intercropping system.

Table 4
NPVs of benefit and cost and BC ratios of the castor-based intercropping trial for the most-conservative, 5-year and 10-year scenarios. The NPV estimates and the BC ratios are medians based on 1000 runs of Monte Carlo analysis using @Risk (Palisade, 2014).

	Most-conservative	5-year	10-year
Regional benefit (AU$, 000)	56.8	142	3500
Trial cost (AU$, 000)	84.0	144	248
BC ratio	0.7	1	14

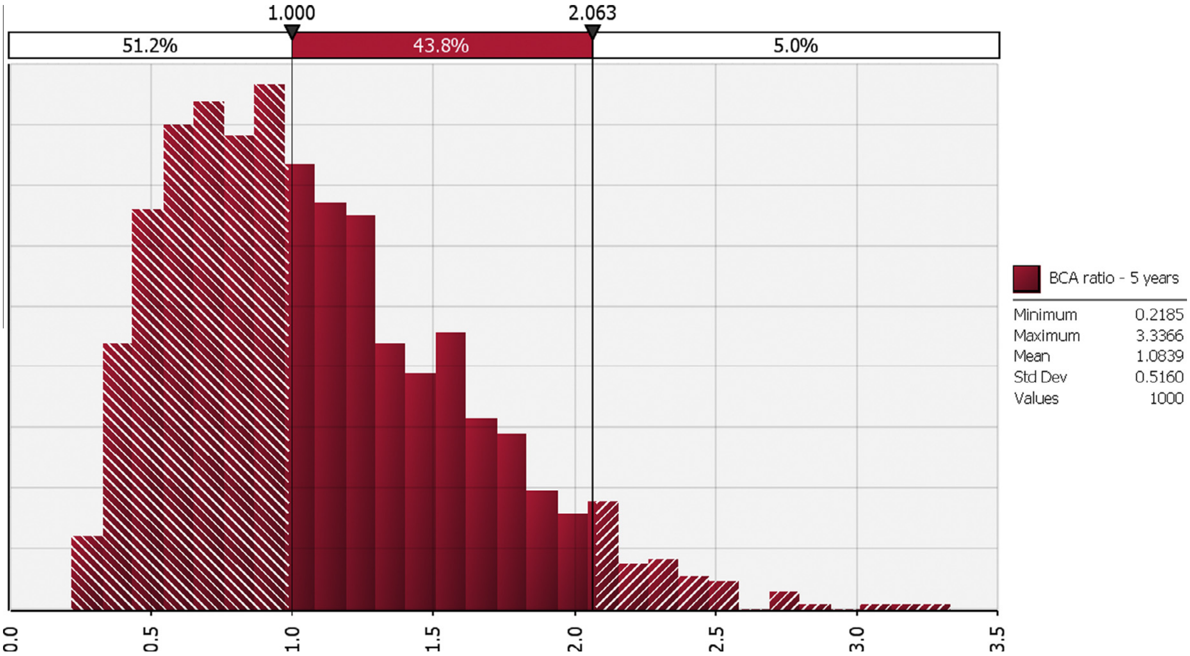

Fig. 5a. The distribution of the trial's BC ratio in 5-year scenario based on 1000 runs.

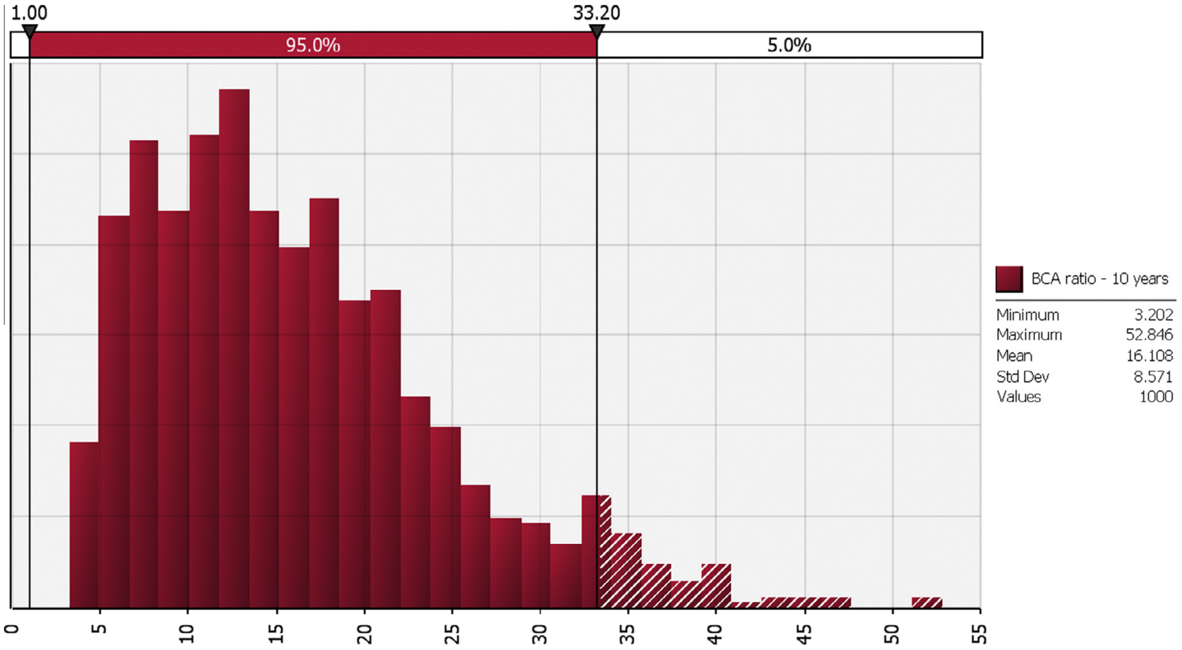

Fig. 5b. The distribution of the trial's BC ratio in 10-year scenario based on 1000 runs.

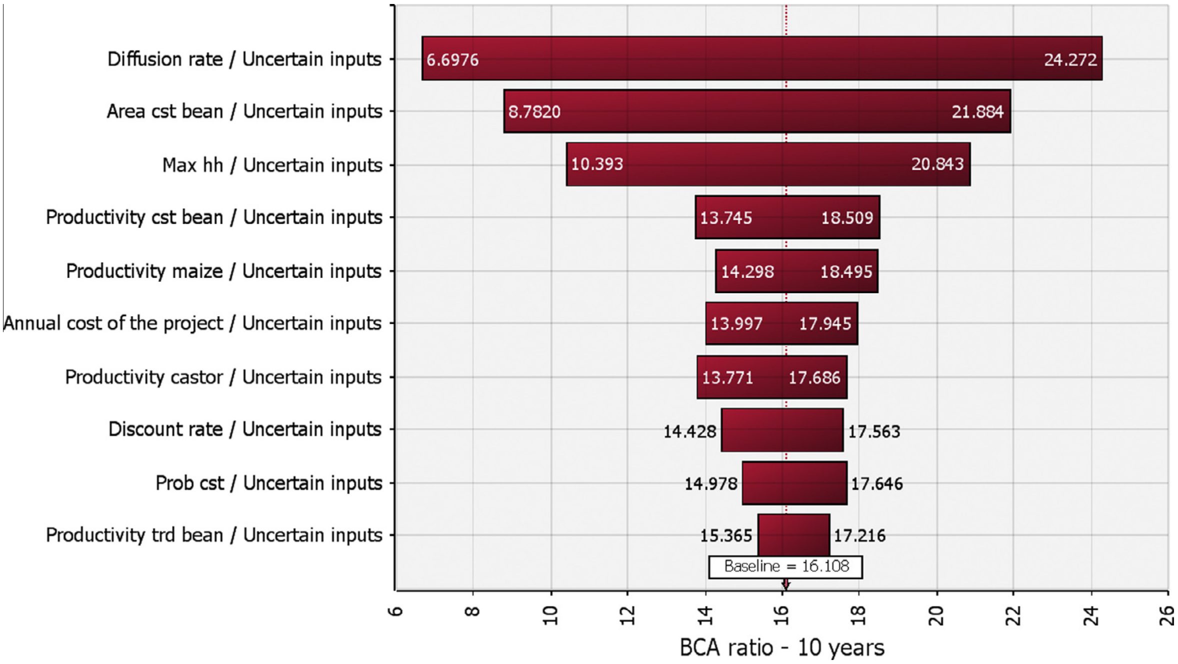

Fig. 6. The input variables ranked by their effects on the BC ratio (life span = 10 years).

Bondre seaweed production

Household benefit cost model

At the household level, the NPVs of the benefit of switching from the traditional to the *bondre* systems are approximately $1800, $3000 and $5000 (in 2012 AUD, median values based on 1000 runs) for the most-conservative, 5-year and 10-year scenarios, respectively. Hence a typical NTB household that adopted the innovation in 2012 and continues to use it in the future will have an NPV of $3000 if the life span of the technology is 5 years and $5000 if the life span is 10 years. On average

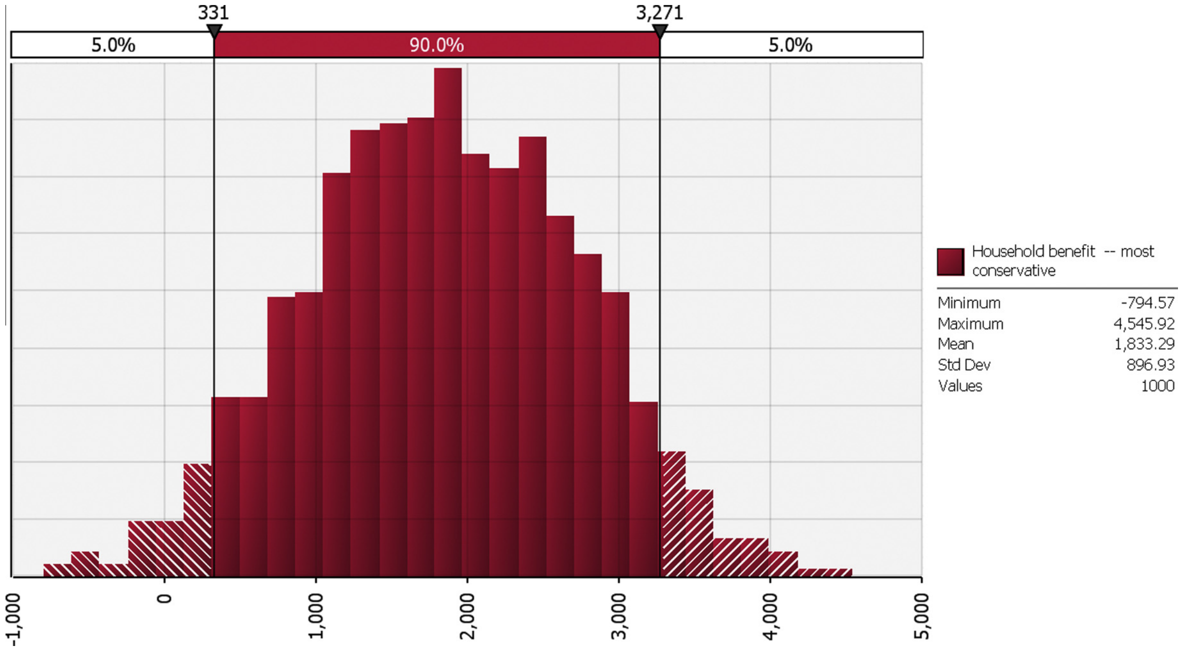

Fig. 7. Distribution of the NPV of the household benefit of adopting the *bondre* system, according to the most-conservative scenario (based on 1000 iterations).

these results mean that the household will have a welfare increase of $500–$600 per year. This is larger than NTB's GDP per capita in 2011 (i.e. 4.274 million Rp or AU$420; (Regional Economic Development Institute, 2013).

Fig. 7 shows the distribution of the NPV of the household benefit for the most conservative scenario, based on 1000 iterations. The top three variables that have the most significant effect on the NPV include income of the raft system in non-storm years, number of *bondre* units per household, and income cycles of the raft system in non-storm years. Both income-related variables are negatively correlated to the household benefit, and the number of *bondre* units per household is positively related to the benefit.

Diffusion model

At the regional level, the total number of households adopting the *bondre* innovation is 200 for the most-conservative scenario. For the 5-year and 10-year scenarios, the numbers are approximately 700 and 16,800, respectively (median values based on 1000 runs in @Risk).

If the diffusion of the technology continues, our conservative prediction is that there will be 700 households using the technology by 2017 under a 5 year life span, and almost 16,800 households by 2022 under a 10-year life span. Both the maximum number of adopters and diffusion rate can greatly influence the total number of households adopting the *bondre* system by 2022.

Regional benefit cost model

Table 5 reports the NPV and their corresponding BC ratios of estimated regional benefits and costs for the *bondre* trial for three scenarios. At the regional level, the NPV of the benefit will reach AU$24.5 million if the life span of the technology is 10 years. On the cost side, the regional NPV will accumulate to about AU$206,000 from 2012 to 2022. In this case, the BC ratio is around 123 and there is only a 1.6% chance that this number is smaller than 1. However, if the life span of the technology is only 5 years, then the BC ratio of the project is approximately 4.6, and there is a 4% chance that the ratio is smaller than 1.

In the most-conservative scenario, the program cost is about AU$77,000, and the benefit for the 200 households that have adopted the technology is approximately AU$211,000. Our calculation results in a BC ratio of approximate 2.7 for the program's investment to date.

Among all the uncertain inputs, the maximum number of adopters has the largest effect on the BC ratio, followed by the top three variables with the highest influence on the household benefit. All four variables are positively correlated to the BC ratio.

Table 5
NPVs of benefit and cost and BC ratios of the *bondre* seaweed production trial for the most-conservative, 5-year and 10-year scenarios. The NPV estimates and the BC ratios are medians based on 1000 runs of Monte Carlo analysis using @Risk (Palisade, 2014).

	Most-conservative	5-year	10-year
Regional benefit (AU$, 000)	211	551	24,520
Trial cost (AU$, 000)	77	120	206
BC ratio	2.7	4.6	122.9

Discussion

Insights from applying the framework

The islands of eastern Indonesia have some of the highest levels of poverty and food insecurity in the country, yet climate change impacts vary widely across islands, requiring locally-specific, no regrets adaptation strategies which can achieve CRD (Butler et al., 2016a). In this paper, we propose an evaluation framework and demonstrate its applicability to two livelihood adaptation strategies developed and trailed in case studies within NTB. One example evaluates intercropping of castor into maize and mung bean crops as an innovative solution to climate variability. In the other, seaweed is grown in *bondre* mesh bags, anchored to the seabed. This innovation is more resilient to storms than the traditional approach of growing seaweed on bamboo rafts.

In both examples we assumed that early adopters of the new technologies will benefit by switching from the traditional practices. The results imply that households who adopt the castor intercropping system will experience an increased annual income of AU$300 to $400, and those adopting the *bondre* system are likely to experience income increases of $500–$600 per year. This is relative to a GDP per capita of approximately $400 per annum in NTB.

Because of the significant increase in household income, we assumed that over time the innovations will gradually spread to other parts of the region and be adopted by more dryland farmers and seaweed growers. In light of the great uncertainty associated with the future diffusion of the new systems, we evaluated a number of scenarios ranging from very conservative, assuming no further uptake and no further benefit to households who have already adopted, to highly optimistic ones involving spread from the current 10's to 100's of households to 1000's and a 10-year longevity. Even under the most conservative assumptions, castor inter-cropping has a near break-even BC ratio, and *bondre* seaweed production has a near 3:1 BC ratio. If use persists for households that have already adopted these strategies, and more households adopt them, the BC ratios could be much higher (see Tables 4 and 5).

In addition to evaluation of economic efficiency, our framework has the capacity to provide guidance on improving effectiveness, that is, the extent to which the strategies attain their objectives. The results identify the inputs which have a major effect on household incomes and the trials' BC ratios. For example, the variables of diffusion rate, production area of mung bean, and the maximum number of adopters have the largest influence on the BC ratio. All three variables are positively correlated to the BC ratios. Therefore, in order to increase the effectiveness of castor-based intercropping, a focus on extension efforts in the implementation and dissemination of the new technology could enhance the economic benefits of the strategy. Research in adopting high-yield varieties of cassava in West African countries suggested that lack of adoption is mostly likely due to a lack of crop reseeding material and information about the technology, rather than a lack of profitability (Johnson et al., 2006). We believe this is the case for the intercropping technology as well. At the household level, the annual benefit of switching to the new systems is at the same scale of GDP per capita in the NTB region, so it is not difficult to demonstrate the profitability to the farmers. However, farmers might sell all the mung bean harvested due to its high profitability and not save seed for future use, resulting in less production area in the future. Considering the large effect of the production area on household benefit, we recommend investment in extension programs that help farmers in planning and in providing free or low-cost mung bean seeds. At the regional level, our results demonstrated the net social benefit of the programs and justify future investment that could increase the diffusion rate and the maximum number of potential adopters.

Contribution and limitations of the framework

As a practical contribution to the evaluation of CRD strategies, we have developed a three-stage quantitative framework built around BCA, simulation modeling and risk assessment. In the first stage, we catalogued differences in the inputs, outputs, costs and prices that determine household net benefit of a new livelihood strategy in comparison to a counterfactual that the household would have implemented in the absence of the innovation. Next, we constructed plausible scenarios to simulate future diffusion of the innovation based on information about diffusion to date. Finally, we summed the benefits to households projected to adopt the innovation and subtracted the trials' implementation costs to calculate the project BC ratios, and applied a Monte Carlo analysis to account for uncertainties. Economic returns of the strategies, expressed as BC ratios, are presented as probability distributions that vary based on systematic sampling across specified ranges for all uncertain inputs.

It is not uncommon to augment BCA with simulation modeling and risk assessment, in the form of Monte Carlo analysis, in project appraisal and impact evaluation (The Treasury of New Zealand Government, 2014; Commonwealth of Australia, 2006; UK Government HM Treasury, 2011). However, such a risk-based BCA technique has not been widely applied in the context of development economics and adaptation projects in developing countries (Takimoto et al., 2008). This may be due to the technique's statistical nature, and a general lack of capacity and data to appropriately conduct such analyzes in developing country contexts (Skewes et al., 2016; Rochester et al., 2016). However, through the two examples we demonstrate that even in locations where climate and economic data are sparse, it is possible to quantify economic costs and benefits of adaptation strategy interventions. A risk-based framework, combined with the local expert opinion, can provide a strong basis for future decision-making on CRD investment and implementation.

In spite of its many assumptions, our primary focus was for the framework to capture some of the essential features of reality, yet remain simple enough to use (Balcombe and Smith, 1999). As such, we attempted to develop a 'requisite' framework that is sufficient in form and content to resolve the issues of concern, that is, evaluating the impacts (as expressed in terms of economic returns and uncertainties) of adaptation strategies to provide guidance on future implementation and CRD investment. However, as it currently stands the framework does have three limitations.

First, although BCA creates a valuable fact base for decision-making (Economics of Climate, 2009), it is challenging to factor in CRD impacts related to subsistence or near-subsistence activities (Stage, 2010). In many developing countries, a large part of agricultural production is carried out by households outside the formal economy. These activities, while crucial for the livelihoods of many people, cannot easily be monetized (Kenter et al., 2011), although their relative contribution to well-being can be estimated (Skewes et al., 2016). As a result, standard BCA techniques cannot be applied to evaluate those investments with a primary impact on subsistence or near subsistence. Similarly, where adaptation strategies aim to build human capital (e.g. through training) or social capital (e.g. by establishing trust and networks), it is not possible to monetize their impacts. This was the case for 11 of the 12 strategies trialled in NTB which included elements of training, awareness-raising or co-management. For this reason and the lack of a clear counter factual, only the castor intercropping and *bondre* seaweed production innovations could be easily evaluated by our framework. It is also notable that even for these, the benefits for human and social capital, plus the ecosystem service benefits, were not considered. In such cases, BCA must be complemented by alternative qualitative methods and measures (Economics of Climate, 2009), which were also trialed in NTB (Butler et al., 2016b).

Second, there is a very high level of uncertainty associated with the diffusion process of agricultural technologies in developing countries. Most empirical research on technological adoption and diffusion has focused on developed economies (Marshall and Brennan, 2001), and has only estimated rates and levels of adoption up to the stage where the process reaches its maximum potential. Little attention has been devoted to the stage when the innovation is abandoned due to factors such as technological substitution (Dinar and Yaron, 1992). In this study, we attempted to predict the diffusion process of the castor and *bondre* innovations over time at the NTB level using the logistic model. Although predictive tools do exist for evaluating the adoptability of agricultural innovations, only a beta version of such a tool is available for the context of developing countries and small landholders (Kuehne et al., 2013). In addition, the Adoption and Diffusion Outcome Prediction Tool (ADOPT) only predicts an innovation's likely peak extent of adoption and likely time for reaching that peak, and it does not take into account when the innovation is abandoned. Finally, 22 questions, regarding both the characteristics of the innovation and the population of potential adopters have to be answered before ADOPT can produce quantitative predictions. In our study, the adoption and diffusion of both innovations only started in 2012, and we had too limited information about the process to provide meaningful answers to these questions. We addressed these issues by making conservative assumptions and by using the Monte Carlo analysis to represent the potential distributions of adopters over time. Still, this is clearly an area for future investigation, considering the influence of the maximum number of adopters and diffusion rate on the project BC ratios.

Third, even though Monte Carlo analysis enjoys the highest recognition in risk assessment tools, it still has some major limitations, including its reliance on the subjective inputs of experts (Bock and Trück, 2011). In the context of international development, this approach also has a relatively high 'entry barrier' because of the possibly lower capacity of local researchers, and also the high cost of the commercially available software package.

Conclusions

Climate change places additional stress on those already in poverty in the developing world, and people previously not in poverty may be pushed into this group as existing livelihood strategies might not be adequate (Tompkins et al., 2013). As a result, international development resources are expected to be stretched to meet the growing demands under a changing climate, and cost-effective international development assistance is an issue of increasing urgency (Nakhooda, 2013).

Until recently, research into the economics of CRD projects in developing countries has been limited (Stage, 2010). To the best of our knowledge, currently there is no existing framework to evaluate the impacts of CRD investment into no regrets adaptation strategies. In this paper, we propose a framework to fill this gap. Built onto a tool set composed of BCA, simulation modeling and risk assessment, the framework strives to capture the essential features of reality and remain simple enough to use. We applied the framework to two innovative adaptation strategies trialed in NTB, and our results explore their economic efficiencies and uncertainties. More importantly, we also provide guidance on future implementation by identifying the key input variables that greatly influence the economic returns of the investment. Finally, it is important to recognize that the economic framework is not applicable to all adaptation strategies, and cannot account for less tangible social and ecosystem service benefits, potentially underestimating impacts. Consequently, our framework should be complemented by qualitative methods and measures.

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