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Insure or Invest in Green Technologies to Protect Against Adverse Weather Events?

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Abstract

This paper analyses investments in green technologies when insurance is also an option. Green technologies are defined to have the power to increase productivity and decrease volatility of future revenues. The insurance options involve the scale and coverage either in a yield insurance or in an index insurance. The stochastic process is a combination of insurable stationary short-run process and non-stationary long run process. The optimal decision rules are solved numerically by stochastic dynamic programming.

The results suggest that the index insurance maintains market based incentives to invest in green technologies whereas a yield insurance substantially decreases investments, as expected. An actuarially fair yield insurance decreases investments at high productivity firms. By contrast if the insurance premiums are supported to the extent that the net loading becomes negative, firms with the lowest productivity have strong incentives to collect the benefits of the subsidized insurance rather than invest in higher productivity and lower risks.

The yield insurance is the most attractive for low productivity firms while the index insurance is the most attractive for high productivity firms. Nevertheless, the demand for actuarially fair index insurance is reduced also amongst the high productivity firms, when the correlation between the yield and the index falls below 50%.

Key words: Investment, insurance, uncertainty, dynamic programming, green technology

Insure or Invest in Green Technologies

to Protect Against Adverse Weather Shocks ?

Introduction

Global warming has enormous economic and social consequences. It is expected to increase the likelihood for crop damages, natural disasters and destructive weather conditions, such as droughts, excess rainfall, storms and floods (IPCC 2007). These adverse weather events have long standing and often irreversible adverse effects within the agri-food sector by jeopardising the possibilities to invest in green technologies. Such technologies have the power to improve productivity, to increase resilience towards adverse weather events, and to decrease emissions that amplify the adverse weather fluctuations in the long run[1].

At the same time, insurability of yield and income losses is challenged if the likelihood for destructive weather conditions increase so that the past weather events are no longer relevant predictors for the future uncertainty (e.g. Kelly and Kleffner 2003; Goodwin 2008) [2]. The weak insurability and market failures within the agricultural insurance market are further exacerbated if climate change implies wide spread persistent, non-stationary characteristics to the risk generating weather processes that have traditionally been experienced local and stationary (*e.g.* Duncan and Myers 2001, McCarl *et al.* 2008).

Given the challenging targets for global agricultural production to meet the increasing demand for food, it is likely that mitigating and adjusting to the climate change requires more investments in green technologies than in the past. Simultaneously, the increasing yield uncertainty and price volatility also increase the need to develop new innovative insurance approaches to better protect farmers against adverse yield, revenue, and income shocks in the short run. As a response to these needs, extensive policy programs have been implemented to promote investments in green

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[1] Typical examples of productivity increasing and risk decreasing green technologies in agriculture are land improvements such as drainage, irrigation, and technologies protecting soil erosion such as no-till and direct drilling technologies.

[2] In insurable market exists a set of indemnities, net of premiums, that at least break even for the insurer and that make the farmer better off than in the absence of insurance (Chambers 1989).

technologies and market for insurance contracts. Also tradable financial services, such as index based insurance contracts, have been designed to better serve the short term risk management targets (Karuaihe *et al.* 2008, Barnett *et al.* 2005; Miranda and Vedenov 2001). Although the supply and adoption of these services has been increasing, such agricultural insurance products have often been promoted by considerable public support, as they would not have emerged in the market without policy interventions (Goodwin 2001). An important policy question then is that how efficient and consistent the policies intervening the insurance markets are in terms of safeguarding farmer income in the short run while also promoting investments necessary to mitigating long term climate change.

The investment literature has highlighted on how the economic incentives of at least partially irreversible investments depend on their expected costs and benefits as suggested by the standard NPV-rule, and in addition on the volatility of their future returns (*e.g.* Dixit and Pindyck 1994, Driffill et al. 2003). Thus, a subsidized yield insurance contract, in which the indemnity payments depend on firm productivity through observed crop damages and losses of the firm, may significantly decrease competitive firm's incentives to invest in productivity increasing and risk decreasing technologies that incur sunk costs and long payback periods. This problem is just one implication of the moral hazard phenomenon (e.g. Smith and Goodwin 1996). If the risk management strategies involve irreversible real investments in green technologies, having the power to increase productivity and decrease volatility, rather than being restricted to a mix of only short term input choices, then the equilibrium conditions and the empirical trade-offs between the choices are expected to differ.

The literature on insurance focuses on the efficiency and behavioural implications of different short run risk management services, such as input choices, mitigation incentives and effort under different insurance contracts (*e.g.* Skees and Reed 1986; Kelly and Kleffner 2003; Mishra and Goodwin 2006; Makus *et al.* 2007), or optimal hedging under multiperil risks (Karuaihe *et al.* 2008). One line of literature analyses optimal insurance conditional on situation in which the insurable risks are more or less correlated with uninsurable background risk. In these literature the background risk is, nevertheless, treated as exogenous (e.g. Vercammen 2001).

Perera (2010) extends the household's risk management problem to investments, consumption, and savings rules, but for being able to derive the closed form decision rules, he imposes insurable losses independent of stochastic asset returns. Recent literature expands to insuring risky investments through different credit, asset or life insurances (*e.g.* Lai and Soumare 2010; Gromley *et al.* 2010, Branger *et al.* 2010). It has also been shown that there is an inverse relationship between the disaster assistance programs and insurance purchases (Cafiero et al. 2007; Goodwin and Rejesus 2008). This gives grounds to postulate also an inverse relationship between the adoption insurance and green investments also under more general settings. In our knowledge, the current literature does not, nevertheless, address the empirical linkages and trade offs between different insurance mechanisms and real investments in risk reducing technologies.

This paper contributes to the literature by analysing the trade-offs between adoption of traditional yield insurances, index based insurances, and investments in green technologies that have the power to increase productivity and decrease volatility of future revenues. The goal is to highlight policy options that are consistent in stabilizing the short term income volatility, while maintaining economic investments to mitigate climate change through improved productivity and decreased volatility in the long run. Our results help in better understanding the trade-offs between the different financial services to trade risks and invest in green technologies that are necessary for mitigating catastrophic risks driven up by climate change.

Our economic model represents a grain grower that has an option to invest in productivity improving and risk reducing technology while also purchasing protection against annual yield losses through an insurance contract. We solve the stochastic intertemporal decision problem numerically using stochastic dynamic programming, because a closed for solution similar to that *e.g.* in Perera (2010) would be infeasible. The resulting optimization problem is then simulated to alternative policy and risk scenarios, such as premium supports, loading rates, and correlation between the yield and the index.

Because the irreversible developments in the climate and production environment may imply non-stationary characteristics to the weather processes that have traditionally been experienced stationary, we allow for a stationary one period yield and income generating process within a longer run more non-stationary process. The producer can hedge against the stationary process through either yield insurance contract, or through an index based contract.

The long run stochastic process is modelled as an endogenous Markovian type process so that the producer can shift the mean productivity and compress the stochastic spread of the productivity process through irreversible real investments. If the investments are postponed, the mean productivity decays and the spread of the stochastic process widens gradually. Conceptually our approach of modelling the linkages between irreversible investments, such as land improvements that increase yields and decrease yield uncertainty, is similar to previous work of Myyrä *et al.* (2007) and Pietola *et al.* (2011).

Subsequent section formalises the economic optimization model. The simulation results are presented thereafter and the last section concludes with remarks.

Economic optimization model

In building the firm's economic optimization model we first identify the one period returns that are augmented by the indemnity functions of alternative insurance options and returns from government programs, such as the direct income supports. Once the one period returns are defined, we convert them to utility and stack them together into the dynamic optimization framework, using the Bellman equation (Bellmann 1957). The one period returns are linked together through stochastic transition equation for the productivity state that defines the mean and volatility of the process. The mean can be shifted and volatility can be decreased through real investments.

Without losses in generality we have normalized the model per one hectare of land and investments are imposed to affect productivity linearly. This assumption is justified to highlight the trade-offs between the different insurance options and investments rather than driving the results by non-linear effects of the investments.

Indemnity payment function for the yield insurance contract

The one period returns are augmented by the yield insurance contract, in which the indemnity payment per hectare ($\tilde{n}_t^{y,i}$) is based on the observed yield losses at time *t* on the farm *i*, as compared to the critical yield (strike; $\overline{\mu}^c$):

$$\tilde{n}_t^{y,i}(\tilde{y}_t^i) = \max\,(\overline{y}_t^c - \tilde{y}_t^i(x_t^i)\,,\,0) \times scale_t \qquad [1]$$

where

$\overline{y}_t^c = \overline{\mu}^c \times cover_t$

$\overline{\mu}^c$ = the critical yield, the strike

$cover_t$ = the share of the coverage at time t

$\tilde{y}_t^i(x_t^i)$ = realization of the stochastic area yield on farm *i* , as a function of the firm's productivity state x_t .

$scale_t$ = scaling factor, *e.g.* the number of contracts

If the critical yield is defined as the average yield in the county, this insurance is often referred to as the area yield insurance contract or the yield index insurance (Barnett *et al.* 2005).

Payment function for the index insurance contract

In the index insurance contract (*e.g.* the weather index based), the payment is a nonlinear function of the index measurements:

$$\tilde{n}_t^{w,i}(\tilde{w}_t) = \max(\overline{w}_t^c - \tilde{w}_t, 0) \times scale_t, \qquad \text{for shortage} \qquad [2a]$$

$$\tilde{n}_t^{w,i}(\tilde{w}_t) = \max(\tilde{w}_t - \overline{w}_t^c, 0) \times scale_t, \qquad \text{for excessiveness} \qquad [2b]$$

where

$\tilde{w}_t$ = the realization of the stochastic index at time *t*

$\overline{w}_t^c$ = the critical index value that triggers the payment

$scale_t$ = the number of contracts.

In this case the payment depends on the realization of the stochastic index value ($\tilde{w}_t$) and the critical index value ($\overline{w}_t^c$). As above, the endogenous choice variables, coverage and scale, can be used to increase or decrease the level of protection. The scale is the number of contracts purchased and the coverage defines the critical index value as compared to a certain strike $\overline{w}^0$, so that $\overline{w}_t^c = \overline{w}^0 \times cover_t$

Please note that, in the yield insurance contract, the indemnity payments and premiums base on the observed losses and they are, therefore, affected by the firm's investments to increase productivity (x_t). Thus, the level of protection and the premium payment, conditional on a given scale, coverage and net loading, decrease with investments and productivity. But in the index insurance, the index values, the payments and the premiums are fully exogenous and, therefore, they are not affected by the investments and productivity of the firm.

One period returns and utility

Summing up the one period revenues and costs we obtain the one period returns ($\tilde{\pi}_t$) of the form[3]:

$$\tilde{\pi}_t = \left\{ \tilde{y}_t x_t + d_t^{\psi} \left[\tilde{n}_t^{\psi} - (1+\lambda)(1-\mu) p_t^{\psi} \right] \right\} p_t^{y} - MC_t + S_t - u_t\, p_t^{u} \qquad [3]$$

where x_t refers to the state of productivity. Parameters λ *and* μ denote rates of loading and premium supports so that the product $(1+\lambda)(1-\mu)$ is the net loading rate for the contract.[4] The availability of the insurance contract of type ψ is indiced by d^{ψ}. The indemnity payment of the yield insurance, the tick price in the index insurance and the corresponding premium rates p_t^{ψ} are normalized so that the price of output p_t^{y} can be collected as the common factor as indicated in [3]. To avoid the Bellman's (1957) curse of dimensionality, the available insurance options are within each simulation either a yield insurance or an index based derivative but not both of them simultaneously. The terms *MC* and *S* refer to marginal production cost and direct income supports. The investment decision is denoted by lower case u_t and its unit price is p_t^{u}.

Those insurance and derivatives contracts that are defined actuarially fair are denoted later on by "*Fair*" and in this case the price of the contract equals to the expected pay-off, *i.e.* $p_t^{\psi} = E\left[\tilde{n}_t^{\psi}\right]$ for both ψ. The standard deviation of the yield (σ_y) is estimated at the experimental yield data for spring wheat over the years 1970-2009 (MTT Agrifood Research Finland)[5]. Around the mean productivity the standard deviation is estimated at 22% of the mean. To maintain consistency in the measurements, the variability of the index (σ_{ind}) is also imposed at 22% of its mean. Given the mean and standard deviation of the yield and the index, the relevant vectors of annual yield and index values are drawn within each iteration stage from the normal distribution with a fixed seed.

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[3] To simplify notation we have suppressed the superscript indicating firm *i*.

[4] The loading can be due to transaction costs in paying out the indemnites and collecting the premium payments. The sum of these is collected as the share adding to the premium rate. Ee do not make a distinction betwee the loading of payouts and the loading in premiums as Chambers and Quiggin (2000, p. 237).

[5] The total number of yield observations in these data are 134.

Cholesky decomposition is then used to simulate vectors for the yield and the index with a given correlation, *i.e.* with a given basis risk in the index insurance.

Farmer risk preferences are described by a Constant Relative Risk Aversion (*CRRA*) in the utility (*U*) function

$$U(\pi_t) = (1-\theta)^{-1} \pi_t^{(1-\theta)} \qquad [4]$$

where π_t is defined in [3] and θ is the *CRRA* coefficient measuring risk aversion and is set at 0.8[6].

The Dynamic Programming Model

The stochastic dynamic programming (DP) model represents a spring wheat grower who cultivates a unit of arable land with stochastic revenues. She has three decision variables to be decided simultaneously each period. The first is the amount of real investment that increases next period expected productivity and decreases the yield/revenue uncertainty, as described more in detail later. The other two decision variables determine the level of protection purchased through the insurance contract. The choice variables concerning the contract are the coverage and the scale as they are defined in equations [1] and [2]. And as described above, two types of contracts are considered, but only one of them in each simulation run. In one set of simulations the farmer can choose the amount of investments and a yield insurance with the preferred coverage and scale options therein [1]. In another set of simulations, the available contract is an index insurance with the corresponding options [2]. For simplicity and without any losses in generality, we have chosen to simulate the index insurance with the payment function for shortage [2a] only. The coverage and scale variables are both bounded in all simulations within the range of [0,1.5]. The corner solution of choosing value zero for the scale or coverage implies that the farmer decides not to purchase the contract at all[7].

The insurance specific optimal value function, *V*, satisfies the Bellman equation of the form:

[6] θ is necessarily bounded within [0,1]. θ =0 would imply risk neutrality and θ=1 would imply logarithmic utility.
[7] If the firm chooses zero scale (coverage), then the coverage (scale) becomes redundant.

$$V(U_t \mid \psi) = \underset{\{u,\text{cover},scale\}}{Max} \left\{ E_t[U_{t+\tau}(\pi) \mid x_t, \varepsilon_t, \psi] + \beta E_t \left[V_{t+1}(U_{t+1}) \mid \psi) \right] \right\}, \quad t \le T-1, 0 < \tau < 1 \qquad [5]$$

where ψ defines exogenously whether the yield insurance or the index insurance is available.

The opportunity cost for capital is denoted by the discount factor β, and E is the expectations operator. In theory, the problem has an infinite horizon, but because it will be solved numerically, the time horizon (T) is set as finite, at 30 years, which is long enough to get the policy rules to converge.

The small time increment (τ) is used to define within one time period (t), *e.g.* a growing season, the necessary condition that the choice of insurance is made before information about the stochastic yield is realised within that time period. Since this part of the stochastic process is stationary, it does not have implications to the next period state and, accordingly, we can take expectation (E_t) of the utility across all outcomes conditional on the stochastic non-stationary state within that period.

The next period productivity state (x_{t+1}) is controlled for by the annual gross investments (u_t) through the transition equation:

$$x_{t+1} = (1-\rho)(1+u_t)x_t + \varepsilon_{t+1} \qquad [6]$$

where annual gross investment is normalized between [0, 0.3] and the exogenous depreciation rate (ρ) is imposed at 1%.

The longer run uncertainty over the productivity process (ε_t) is approximated by a 3x3 Markovian-type probability matrix. Productivity is allowed to have three states. In the middle state, referredas the "*expected productivity*", the productivity follows the expected path defined by the annual investments and the depreciation rate over time. The "*lower than expected*" productivity state is 50% below, and "*the higher than expected*" productivity state is 50% above the expected productivity. Without losses in generality, we have normalized the average of the "*expected productivity*" within the sample equal to one.

At the average productivity ($x_t = 1$), the probability matrix (*Prob*) defining the probabilities for the productivity shocks (ε_t) between the three states is[8]:

$$Prob\ (x_t{=}1) = \begin{bmatrix} 0.5 & 0.5 & 0 \\ 0.325 & 0.35 & 0.325 \\ 0 & 0.5 & 0.5 \end{bmatrix} \qquad [7]$$

Thus, the probability that productivity remains unchanged either above, at, or below the expected productivity is 50%, 35% or 50% (the diagonal elements). If the current state is "*higher than expected*" (the first row) there is 50% probability that the productivity remains unchanged but also 50% probability that it will decrease to "*expected productivity*". Similarly, if the current state is at "*expected productivity*" there is 35% chance that it will remain unchanged, but also 32.5% probability that it will decrease (increase) to "*lower (higher) than expected*" productivity.

To control for the risk reducing characteristics of investments, the probability matrix is defined to depend on the endogenous "*expected productivity*" (x_t) so that the higher the expected productivity the lower is the uncertainty and the more the probability matrix is compressed towards the middle column[9]. The larger the entries in the middle column are, the higher is the probability that the next period productivity equals the expected productivity and, hence, the lower the risk is. Technically, we multiply the middle column entries by the productivity and then rescale the non-zero off-diagonal entries so that within each row the sum of probabilities equal to one as required. All entries are bounded between [0,1].

The boundaries of the endogenous choice variables and exogenous parameter values of the model are summarized in Appendix.

[8] The probability matrix could be defined larger than 3x3, but the current definition is general enough to highlight the impact of uncertainty in the decision rules. Please note that the elements in each row necessarily sum up to one.

[9] The probability matrix is defined symmetric and mean preserving, whereas the expected next period productivity is shifted/decayed throuigh the transition equation. Alternatively, one could maintain the upward potential and move only the probability for low state to the probability of expected or high state. But in this case the probability distribution would not be mean preserving.

Results

Investments

We first examine investments in the benchmark scenario in which the farmer does not have access to an insurance contract (Figure 1). In this case the insurance mechanisms do not affect the investment decisions but the market is also incomplete in the sense that there is no market for risk. Under this set up of market based incentives, the low productivity firms will invest the maximum amount until productivity reaches sufficiently high level, which is the average productivity multiplied by 1.4. Thereafter, the investments begin to decrease with increasing productivity almost linearly towards the corner solution at the point in which productivity is 2 times the mean. This upper bound for the productivity is imposed in the algorithm for technical reasons and it is a technical characteristic of the stochastic model that investments decrease when the productivity approaches the maximum.

If fair index based contract is available, with a perfect correlation between the index and the yield, the above described market based incentives to invest are still maintained as expected. The investment pattern coincides with a negligible numerical deviation to the no-insurance benchmark.

Fair yield insurance contract, nevertheless, deviates the optimal investment pattern significantly from the no-insurance benchmark. The insurance maintains the incentives to invest at low productivity levels, but it decreases incentives to invest, when the firm's productivity is higher than the average (=critical yield, the strike in the indemnity function).

Net loading of the yield insurance affects substantially the optimal scale and coverage of the insurance and also the optimal investments. If the yield insurance is subsidized as much as 40% in excess to the transactions costs (*i.e.* net loading is -40%), then the insurance fully depletes the incentives to invest at low productivity levels (Figure 2). In this case utility is maximized by continuing with low productivity and high yield volatility to collect indemnity payments through the subsidized insurance, rather than to invest in productivity improvements and lower risks. If the insurance is not subsidized and the firm has to pay a positive loading, the demand for the insurance decreases and incentives to invest increases at productivity levels that are higher than the average.

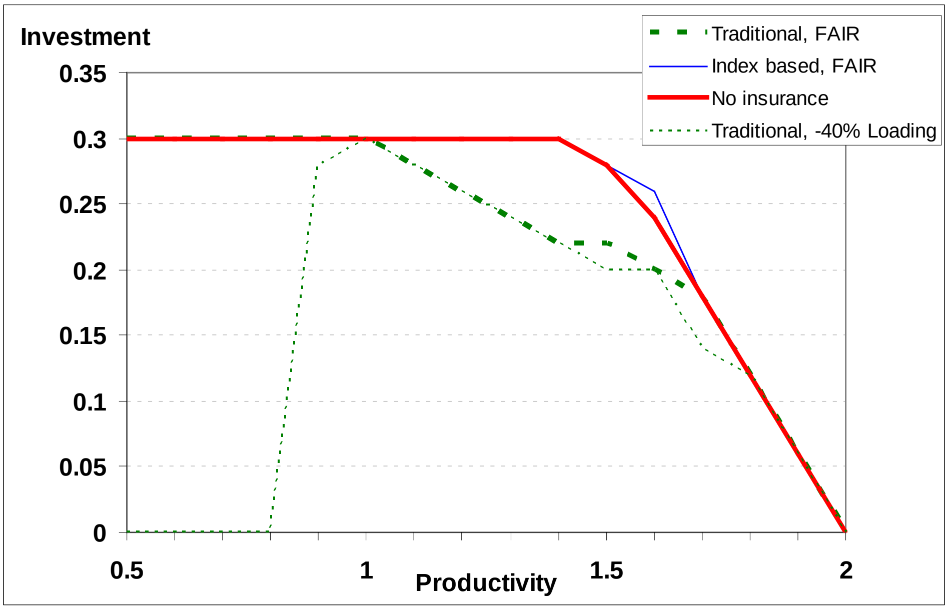

Figure 1. Investmens (u_t) conditional on productivity (x_t) under the cases of no insurance, traditional yield insurance (either fair or subsidized to -40% loading) and fair index insurance. Perfect correlation between the yield and the index. The strike ($\bar{\mu}^c$) is set at productivity of 1.

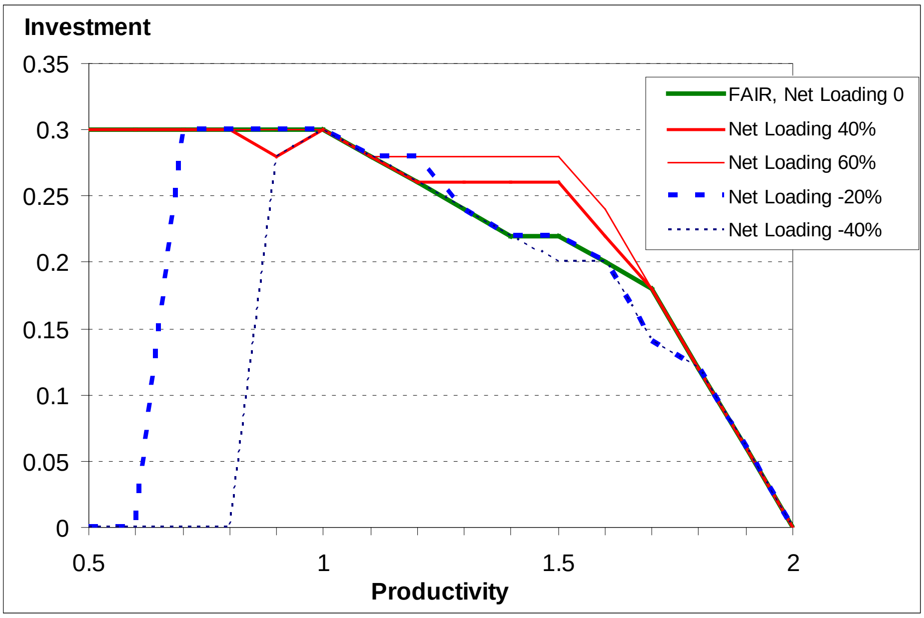

Figure 2. Investment under traditional yield insurance conditional on productivity (x_t) and alternative net loading rates, net of premium supports. The strike ($\bar{\mu}^c$) is set at productivity of 1.

Demand for yield insurance contract: scale and coverage

The pattern for the optimal scale and coverage of the yield insurance are similar when the insurance is either actuarially fair or subsidized to the extent that the net loading is negative. For fair contract, they both decrease quickly when productivity increases above the strike. If the insurance is subsidized to the extent that the net loading is negative 20%, the coverage stays at the maximum until productivity reaches 1.4.-1.5 times the strike and, thereafter, they drop down to zero when productivity increases further. At very high subsidization, implying -40% net loading, the optimal scale and coverage stay at maximum also in the highest possible productivity levels. But if net loading rates are negative the scale and coverage both decrease quickly with productivity when productivity exceeds the strike. If net loading exceeds 40% the loading remains well below the maximum even at the lowest productivity levels.

It is notable for these models that around the strike productivity, the different contract options and farmer access to more or less subsidized insurance mechanisms do not make any difference for the optimal investments (Figures 1 and 2). In other words, around the strike, the insurance and index contracts do not distort the market driven economic incentives to invest, even if the adoption of these contracts are subsidized through premium supports.

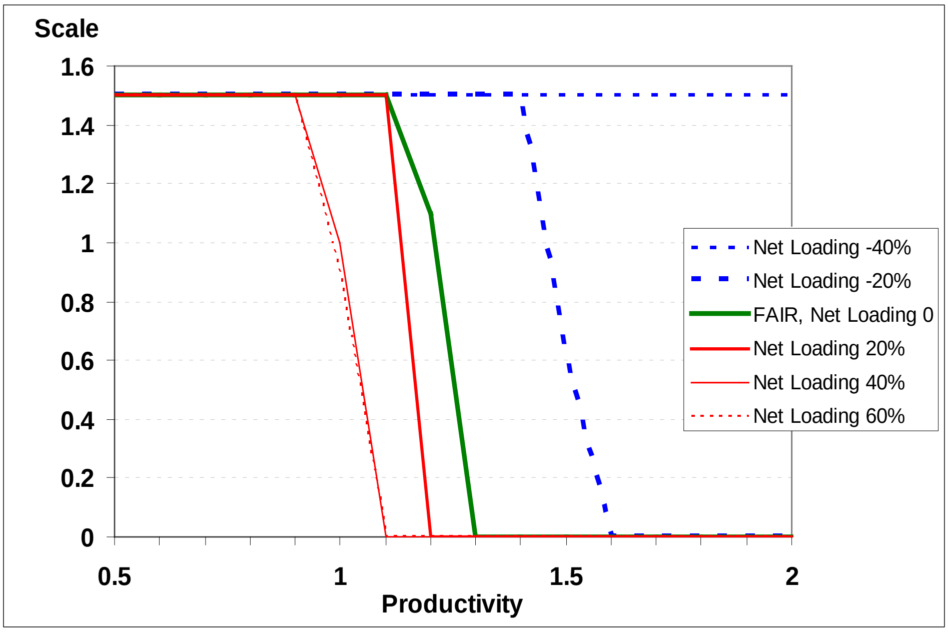

Figure 3. Scale in traditional yield insurance conditional on productivity (x_t) and net loading, net of premium supports. Strike ($\bar{\mu}^c$) set at productivity of 1.

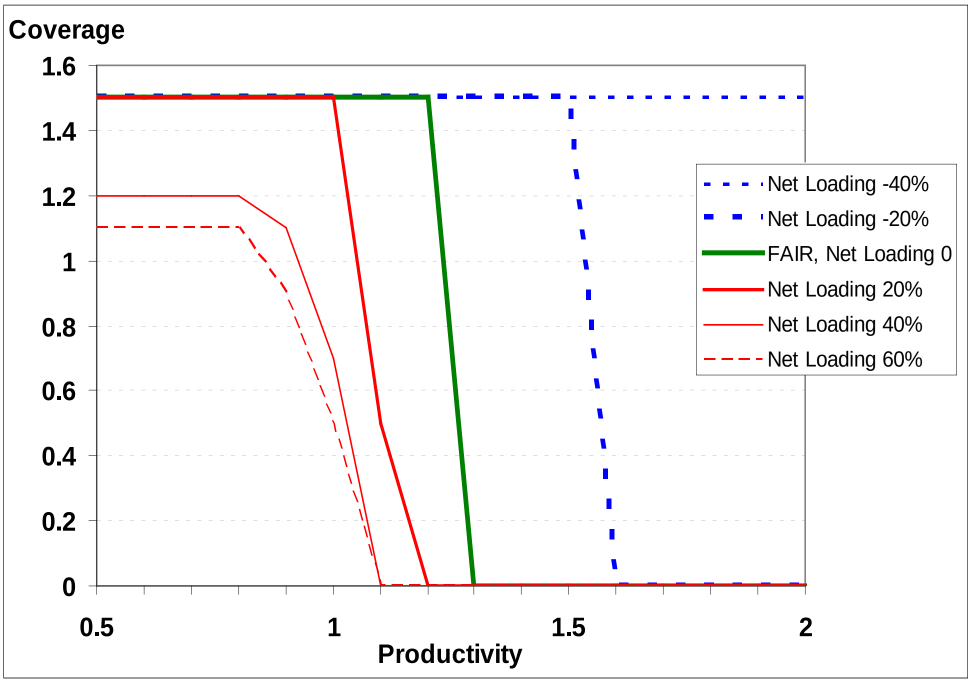

Figure 4. Coverage in traditional yield insurance conditional on productivity (x_t) and net loading, net of premium supports. Strike ($\overline{\mu}^c$) set at productivity of 1.

Demand for index insurance contract: scale and coverage

The demand for the index insurance, when it is measured by the scale, increases first with productivity and, when productivity reaches 1.4 times the strike the scale stays more or less constant (Figure 5). The demand depends on how well the index correlates with the yield and the correlation makes a large difference in particular at high productivity levels. As long as the correlation exceeds 60%, the scale remains almost as strong as in the benchmark of 100% correlation, but it begins to decrease when correlation decreases to below 50%. A decreasing correlation decreases the demand most at high productivity levels as indicated by the dotted line for 20% correlation in Figure 5. When correlation decreases towards the 10% net loading rate or below it, the demand falls to zero for all productivity levels.

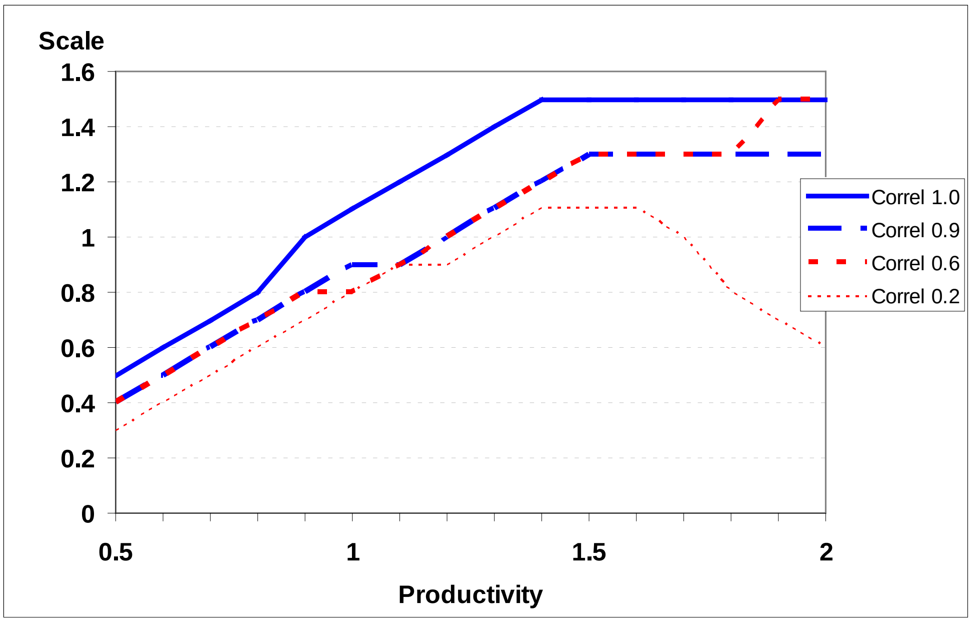

Figure 5. Scale of index insurance conditional on the correlation between the index and the yield. net loading imposed at 10%. Strike ($\overline{\mu}^c$) set at productivity of 1.

At the given 10% net loading, the optimal coverage in index based insurance remains constant across different productivity levels, but it decreases with the correlation between the index and the yield. The coverage remains above 50% when the correlation is at least 20%. When the correlation decreases below 20%, *i.e.* towards and below the 10% net loading rate, the optimal coverage decreases quickly to zero

Over all the demand pattern of an index based insurance with respect to productivity differs from the corresponding demand pattern of yield insurance (Figures 6 and 7). When the index correlates perfectly with the yield and the net loading increases to 20-40%, the demand decreases the most amongst the low productivity firms, while the demand remains high amongst high productivity/low volatility firms. But when the net loading increases at large loading rates (*e.g.* 60%) the demand decreases quickly at high productivity and low volatility levels. In the case of yield insurance, an increase of the net loading rate decreases the demand in high productivity/low volatility firms while the demand remains unchanged amongst low productivity/high volatility firms.

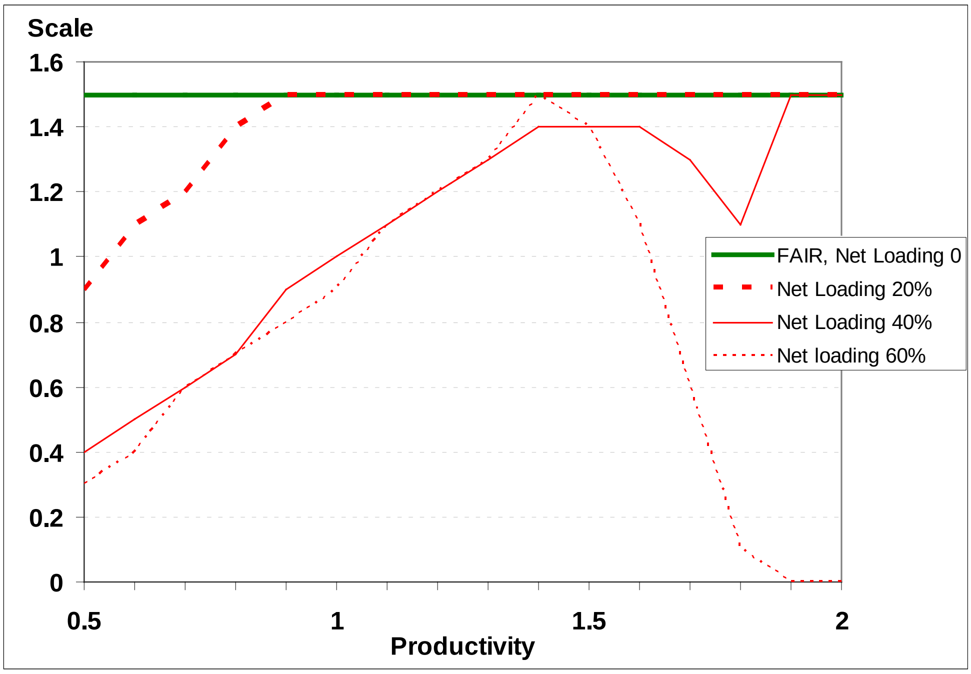

Figure 6. Scale of index insurance conditional on productivity and net loading. The index and the yield are perfectly correlated.

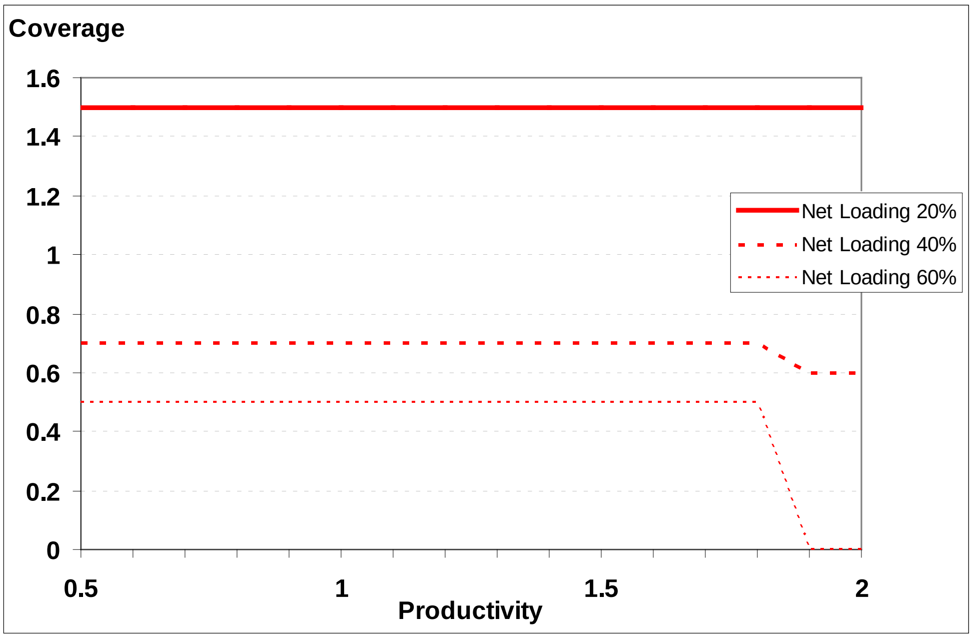

Figure 7. Coverage of index insurance conditional on productivity and net loading. The line for "Fair" would coincide with the line for "net loading 20%". The index and the yield are perfectly correlated.

Concluding Remarks

Our results highlight that economic incentives to invest in productivity increasing and risk decreasing green technologies depend substantially on the insurance mechanisms available for farmers to protect themselves against short term crop failures and income losses. Therefore, the design of more or less tradable short term agricultural safety nets do matter in farmer incentives to improve their productivity and to mitigate more persistent, long run climate change, through the necessary real investments. It is evident that index based insurance contracts would be less market distorting and more consistent than the traditional yield insurances with respect to improving competitiveness and building resiliency through green investments. The efficiency of the index based measures as short run safety nets is, nevertheless, a concern as their adoption depends crucially on how well the index and the yields are correlated. Our results suggest that, at 10 % net loading for example, the demand remains strong as long as the correlation exceeds 50%. Thus, our results provide promising signals on potential to design index based insurance contracts that have strong demand amongst firms with different productivity levels.

The optimization results support the view that index based insurance and derivatives contracts, maintain the (incomplete) market based incentives to invest in productivity increasing and volatility decreasing technologies as expected. But the traditional yield insurance maintains the market incentives to invest only at low productivity levels even if it is actuarially fair. The yield insurance substantially decreases incentives to invest, when the firm's productivity is higher than productivity at the strike. Net loading further affects the optimal scale and coverage of the yield insurance and, therefore, also the optimal investments. If the yield insurance is subsidized to the extent that its net loading decreases to negative, then the insurance quickly depletes the incentives to invest at low productivity firms. In this case it is optimal to continue with low productivity and high yield volatility, and to collect indemnity payments through the subsidized insurance, rather than to invest in productivity improvements and lower volatility. If the insurance is not subsidized and the firm has to cover the true cost of loading, the demand for the yield insurance decreases and incentives to invest increase towards the market based incentives.

In the trade policy taxonomy, agricultural supports are categorized as coupled or decoupled depending on their marginal effects on production decisions. But in the case of premium supports on traditional yield insurances, this market distortion and production incentive effect is best characterized as dis-coupled rather than coupled or decoupled. Similar to the moral hazard problems, as revealed by the closed form results in more static frameworks, our numerical simulations indicate that the premium supports on traditional yield insurance substantially discourages productivity increasing and volatility decreasing investments. Premium supports keeps low productivity firms trapped at their at low productivity and high volatility by postponing productivity increasing and volatility decreasing investments.

The same taxonomy links also to the regulations under the European Common Agricultural Policy (CAP), as it is not quite consistent to categorize the premium supports in the same group as the coupled supports within Article 68. The CAP regulations further require that premium supports can be granted only for insurance programs in which the indemnity payments are determined by the observed on-farm losses, not indirectly by index values. This regulation hinders developing new and innovative index based contracts consistent with policy goals to improving the competitiveness and resiliency of the European agricultural sectors.

The demand for yield insurance and index insurance differ amongst firms with different productivity. The yield insurance is the most attractive for low productivity firms while an index insurance is the most attractive for high performance firms. The demand for an actuarially fair yield insurance contract decreases quickly when productivity of the firm increases as compared to the strike. The demand of fair contract drops down to zero when the productivity exceeds the strike by 20%. When the net loading is positive so that the producer pays a price from the yield insurance, the demand drops quickly when the productivity increases above the strike. Premium subsidies that make the net loading rates negative shift the productivity threshold upwards so that a –20% net loading, for example, maintains the demand until productivity increases 40-50% above the strike. Net loading of -40% is sufficient to maintain the demand at the maximum also for the highest productivity firms.

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Appendix. The parameter values and the boundaries of choice variables and in the DP-model.

Parameter/variable	*Value, or range*
Time horizon, T	30 years
Opportunity cost of capital, r	3% per year
Investment, u_t	[0, 0.3]
Scale	[0, 1.5]
Coverage	[0 , 1.5]
Productivity, x_t	[0.5, 2.0]
CRRA coefficient of risk aversion, θ	0.8
Standard deviation of the yield, σ_y	22% of the mean
Standard deviation of the index, σ_{ind}	22% of the mean
Net Loading $(1+\lambda)(1-\mu)$	[-60%, 60%]
Correlation between the yield and the index	[0, 1]
Price of yield p_t^y	150
Price of investment, p_t^u	1,500
Depreciation, ρ	1%
Marginal Cost, Direct income supports MC, S	500
Direct income supports, S	500

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