The economic insurance value of wild pollinators in almond orchards in California

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Abstract: Biodiversity can provide an economic insurance value against the uncertain provision of ecosystem services for risk-averse economic agents. For uncertain pollination services, we determine the risk premium and the economic insurance value of wild pollinators in almond orchards for a risk-averse farmer with alternative types of risk-preferences. For this, we describe pollination services as a distribution, which can be analysed by statistical methods. We convert this pollination distribution into an income distribution for the farmer relying on pollination services. Further, we develop an ecological-economic framework to determine the risk premium and insurance value of wild pollinators in general for different types of risk preferences, and apply this model to empirical data on flower visits of honeybees (*Apis mellifera*) and wild pollinators such as several wild bee species (e.g., *Andrena* spp., *Osmia* spp.) and other wild insect pollinator species to almond trees in California. Results show that wild pollinating species can both increase or decrease the riskiness of a pollination and thus, income distribution and therefore can or cannot have an insurance value. That is, the economic insurance value of wild pollinators is dependent on the exact type of risk preferences of the farmer.

JEL-Classification: Q57, Q12

Keywords: insurance value, types of risk preferences, valuation, risk, pollinator species, almond, pollination, ecosystem services, biodiversity

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1 Introduction

Pollination is an important regulating ecosystem service provided by various insects, bats and also several managed pollinator species e.g. the European honey bee (Pejchar and Mooney 2009). Many of the pollinator-dependent crops rely on pollination services by the European honey bee. However, wild pollinator species (e.g. wild bee species and hover flies) are known to be effective pollinators, too, that may also forage under more inclement weather conditions than the honey bee (Garibaldi et al. 2013). From an ecological point of view, wild bees can have an ecological insurance effect against the honey bee loss as they can compensate the pollination services in $> 90\%$ of the watermelon crop farms studied (Winfree et al. 2007). Still, as pollination services are dependent on various exogenous and uncertain factors, farmers relying on these services face a risk. Further, farmers are known to be risk-averse in most cases (Binswanger 1980, Dillon and Scandizzo 1978).

We investigate whether and to what extent wild pollinating species have an economic insurance value against the uncertain provision of pollination services for risk-averse farmers. To that end, we apply statistical methods to analyze the probability distribution of pollination for different combinations of pollinating species. We analze the mean, standard deviation, coefficient of variation and the skewness to evaluate the distribution of pollination services. An increase in skewness is linked to a reduced down-side risk (Di Falco and Chavas 2009). Data comes from a case study of almond orchard farmers in California. We use a variation of the ecological-economic model developed by Baumgärtner (2007) and Baumgärtner and Strunz (2014). In this model, pollination is risky and is therefore described as a random variable that follows a probability distribution which depends on the diversity of pollinators. Each potential set of pollinator species thus constitutes a particular distribution of pollination and, thus, an income or ecosystem service lottery (Crocker et al. 2001). Further, we investigate different alternative risk preferences of the farmer. In particular, we assume the following alternative types of risk preferences:

- constant relative risk aversion (CRRA)

- constant absolute risk aversion (CARA)
- mean-variance risk aversion.

For given type of risk preferences the economic insurance value of some pollinator species is then defined as the decrease in the risk premium of the income lottery due to that additional pollinator species.

We apply this model to data from an existing data-set by Klein, Brittain, et al. (2012) on species-specific flower visits in almond orchards in California. First, we convert the pollination probability distribution for each set of pollinator species into an income probability distribution using also agronomic and economic data. Second, we use statistical methods to analyze the resulting income probability distribution in terms of its mean, standard deviation, coefficient of variation and skewness related to the diversity of pollinators. And third, we determine the economic values of interest - namely the risk premium and the insurance value.

Preliminary results show that expected income of farmers increases with an increase in pollinator diversity. However, the standard deviation of income also increases with higher level of pollinator diversity, as pollinator diversity extends the range of the income distribution. Thus, wild pollinating species do not stabilize the income distribution per se. Yet, the coefficient of variation - as a measure of normalized, i.e. relative risk - decreases when pollinator diversity increases. This indicates that wild pollinating species can reduce relative income risk. The skewness decreases but remains slightly right-skewed with pollinator diversity which indicates little upside risk.

We found different effects on risk premium and insurance value of wild pollinators depending on the exact type of risk preferences. For the CRRA utility function the risk premium decreases with higher pollinator diversity, leading to a positive insurance value, whereas for the CARA and the mean-variance utility function the risk premium decreases, thus, leading to a negative insurance value of wild pollinators for almond farmers. That is, whether wild pollinator species do or do not have an insurance value against the uncertain provision of pollination services for the farmer does not only depend on the probability distribution of pollination but strongly depends on the farmer's exact type of risk preferences.

2 Setup and Concepts

2.1 Ecological-Economic Framework

We used a variation of the model developed by Baumgärtner (2007) and Baumgärtner and Strunz (2014) to determine the risk premium and the insurance value of pollinator diversity. Additionally, we used different different types of risk-preferences to investigate the effect of risk preferences on the risk premium and insurance value.

Consider s as the amount of pollination service. As the ecosystem service depends on the level of biodiversity (v), the pollination depends on the level of the diversity of pollinators. The level of biodiversity v is captured by different combined pollinator groups. We consider honey bees only; honey bees and pollinators from the other species group, and the combination of the honey bees, other species group and wild bee species group. Therefore, v can be

- h for biodiversity represented by the honey bee group only,
- ho for biodiversity represented by the honey bee and the other species group combined,
- how for biodiversity represented by the honey bee, the other species group and the wild bee species group combined.

Considering only the wild pollinators theoretically, v can also be ow.

Pollination is risky, so s is a random variable, described by a probability density function $f_v(s)$. The index v denotes that the probability distribution of pollination depends on the level of biodiversity v.

The farmer's net income y is given by the production function:

$$y = p \cdot s, \tag{1}$$

where p is a factor which includes the average weight of one almond developed from one flower due to pollination services (s) and the market price for these almonds for the year in which the data on flower visits by the pollinators were recorded. As pollination is a random variable, income y is also a random variable. The farmer chooses, then, a level of biodiversity (v) and, thus, a particular distribution of their income y. This can be seen as an income lottery (Crocker et al. 2001).

The farmer's utility is given by the von Neumann-Morgenstern expected utility function. It reflects the farmer's preferences over their uncertain income y:

$$U = \mathcal{E}_v[u[y]]. \tag{2}$$

$\mathcal{E}_v$ is the expectancy operator under a level of pollinator diversity v. $u(y)$ is a Bernoulli utility function, which is increasing ($u' > 0$) and strictly concave ($u'' < 0$). That is, the farmer is non-satiated and risk-averse.

To analyse the effect of different types of risk preferences, we investigate three alternative types of risk aversion, namely: constant relative risk aversion (CRRA), constant absolute risk aversion (CARA) and mean-variance risk aversion.

Constant Relative Risk Aversion

We assume that $u(y)$ is the Bernoulli utility function:

$$u(y) = \frac{y^{1-\rho} - 1}{1 - \rho}, \tag{3}$$

where $\rho > 0$ measures the constant degree of relative risk-aversion of the farmer (Arrow 1965, Pratt 1964). The farmer's von Neumann-Morgenstern expected utility function is then

$$U = \int_0^\infty \frac{y^{1-\rho} - 1}{1 - \rho} f_v(y) ds. \tag{4}$$

Constant Absolute Risk Aversion

Here $u(y)$ is the Bernoulli utility function:

$$u(y) = -e^{-\rho y}, \tag{5}$$

where $\rho > 0$ measures the constant degree of absolute risk-aversion (Arrow 1965, Pratt 1964). Thus, the von Neumann-Morgenstern expected utility function is then

$$U = -\int_0^\infty e^{-\rho y} f_v(y) ds. \tag{6}$$

Mean-Variance Risk Aversion

For the mean-variance risk aversion the utility function is:

$$U = \mathcal{E}_v[y] - \frac{\rho}{2} \left(SD_v[y]\right)^2. \tag{7}$$

where SD_v is the standard deviation of income and $\rho > 0$ measures the degree of risk-aversion.

2.2 Statistical Methods

We use statistical numbers to analyse the income distribution of the farmers. We analyse the mean, standard deviation, coefficient of variation and skewness of the income distribution. The mean is calculated by:

$$\mathcal{E}_v[y] = \int_0^\infty y \cdot f_v(s) ds. \tag{8}$$

The standard deviation (SD_v) of income is:

$$SD_v[y] = \sqrt{\int_0^\infty (y - \mathcal{E}_v[y])^2 \cdot f_v(s) ds}. \tag{9}$$

It is an absolute measure for the dispersion and is in units of income. In addition, we determined the coefficient of variation, which gives a relative measure for statistical dispersion as a percentage of expected income:

$$CV_v[y] = \frac{SD_v[y]}{\mathcal{E}_v[y]}. \tag{10}$$

Further, we calculate the skewness of the income distribution which is given by:

$$g_v[y] = \sqrt{n}\frac{\sum_{i=1}^n (y_i - \mathcal{E}_v[y])^3}{(\sum_{i=1}^n (y_i - \mathcal{E}_v[y])^2)^{3/2}.} \tag{11}$$

The skewness measures the asymmetry of the income distribution. Right-skewed income distributions are linked to low down-side risks, whereas left-skewed income distributions are related to high down-side risks.

2.3 Risk Premium and Insurance Value

For given types of risk preferences we determine the risk premium R, the certainty equivalent CE and the economic insurance value V. The risk premium is defined by

$$u(\mathcal{E}_v[y] - R) = \mathcal{E}_v[u[y]] \tag{12}$$

(Kreps 1990, Varian and Norton 1992). The risk premium is that amount of money that leaves the farmer equally well-off regarding their utility for both situations: Playing the risky lottery or receiving the expected income for sure minus the risk premium.
With given utility functions the risk premium R is defined for each type of risk preference:

CRRA

$$R_v = \int_0^\infty p \cdot s f_v(s) ds - \left(\int_0^\infty ((p \cdot s)^{1-\rho} - 1) f_v(s) ds + 1 \right)^{\frac{1}{1-\rho}}. \tag{13}$$

CARA

$$R_v = \mathcal{E}_v[y] + \frac{1}{\rho} \ln \int e^{-\rho y} f_v(y) ds \tag{14}$$

Mean-Variance

$$R_v = \frac{\rho}{2} (SD_v[y])^2 \tag{15}$$

Additionally, we determine the CE, the difference between the expected income and the risk premium. It is the amount of money the farmer is indifferent between receiving this amount of money or playing the risky lottery:

$$CE_v = \mathcal{E}_v[y] - R_v. \tag{16}$$

Following Baumgärtner (2007), we calculate the insurance value of an additional unit Δv of pollinator diversity as the decrease of the risk premium due to an increase Δv in the level of pollinator diversity v :

$$V_{\Delta v} = R_v - R_{v+\Delta v}. \tag{17}$$

The insurance value is given by the decrease of the risk premium due to an increase in pollinator diversity, namely the other species group and the wild bee species group for each management scenario and type of risk preferences. The economic insurance value for the wild bee species is given by:

$$V_w = R_{ho} - R_{how}. \tag{18}$$

While the insurance value for the other species group is defined as:

$$V_o = R_h - R_{ho}. \tag{19}$$

And for all wild pollinators, the insurance value is defined as:

$$V_{ow} = R_h - R_{how}. \tag{20}$$

That is, if V_v is positive, wild pollinator groups stabilize the income distribution and therefore reduce the riskiness of the lottery. If V_v is negative, wild pollinators increase the riskiness of the lottery. Moreover, the different types of risk preferences then show how farmers evaluate the income distribution by the different pollinator species.

3 Case Study and Data

The data set includes observations of species-specific flower visits in almond orchards in California. That is, it includes the frequencies of flower visits by the different pollinator species and the number of flowers observed and on one tree. For determining the income of the farmer we used data on almond weights and the almond market price.

3.1 Data

3.1.1 Study Sites

Klein, Brittain, et al. (2012) collected data about the visitation frequencies of pollinator species in 23 almond orchards in Colusa and Yolo Counties in the Sacramento Valley in Northern California (38°42' to 38°57'N and 121°57' to 122°14'W). They selected eight organic and ten conventional orchards with different habitat surroundings. Half of the orchards were surrounded by $<5\%$ natural or semi-natural habitat and half by $>30\%$ natural or semi-natural habitat in a 1 km radius (hereafter referred to as natural habitat) (Klein, Brittain, et al. 2012). Klein, Brittain, et al. (2012) also selected five conventional orchards with a low percentage of surrounding natural habitat, but which had an adjacent strip of semi-natural vegetation (10-25 m wide). The strips were along one side of the orchard and consisted of scrubby riparian habitats. The distance between orchards was 1 km at minimum with a mean inter-site distance of 3 km. The organic orchards were certified according to the California Organic Food Act (1990) and did not use any insecticide or herbicide (Klein, Brittain, et al. 2012).

That is, we distinguish between five different management scenarios entailed by the different surrounding habitats when investigating the economic insurance value by wild pollinators:
a) organic orchards, with a low percentage of surrounding natural habitat
b) organic orchards, with a high percentage of surrounding natural habitat
c) conventional orchards, with a low percentage of surrounding natural habitat
d) conventional orchards, with a high percentage of surrounding natural habitat

e) conventional orchards, with an adjacent strip of semi-natural vegetation along one side of the orchard.

3.1.2 Flower visitors and observation frequencies

Klein, Brittain, et al. (2012)'s observations of flower visits were conducted from 25 February to 18 March 2008, at times when temperatures were above 13^{o} C (Delaplane, Mayer, and Mayer 2000), with sunny to lightly overcast skies, and the wind speed was $<2.5\,\mathrm{m\ s^{-1}}$. In each of the 23 orchards, insect flower visitors were observed on three separate days. For each orchard, five trees at the edge of the orchard (near the natural habitat or adjacent strip, when present) and five trees in the orchard interior at 50-60 m (five small orchards) or 100-110 m (18 large orchards) from the edge were observed. All observed trees were in full bloom. At each tree, eight groups of flowers were each observed for 20 s: two each in the inner top, inner bottom, outer top and outer bottom quadrants of the trees. Besides, Klein, Brittain, et al. (2012) documented the flowers observed per time period and the estimated number of flowers on each tree.

Klein, Brittain, et al. (2012) selected flowers for observation so that the observer could see the interior of each flower. Thus, the number of flowers observed per time period was determined by practical feasibility. Observation time per orchard was 26.7 min per orchard and day, and 80 min per orchard in total over 3 days.

With regard to this data, we grouped the different pollinator species as

- honey bee group (h),
- wild bee species group (w), or
- other species group (o).

Honey bee grouping only included the European honey bee, while wild bee species included each wild bee species that belonged to the Apoidea superfamily: here, Klein, Brittain, et al. (2012) observed *Andrena* spp., *Anthophoridae* spp., *Bombus* spp., *Xylocopa* sp., *Dialictus* sp., *Eucera*, *Evylaeus* spp., *Halictidae*, *Hapropoda*, *Lasioglossum*, *Osmia* sp. and *Panurginus* sp.. Other species classified species such as hoverflies (Syrphidae), *Bombyliidae* and all other pollinators that do not belong to the Apoidea superfamily nor to the Apis-bees.

Further, we investigated the following combinations of pollinator groups because only these combinations can bee observed in natural ecosystems (Klein, Brittain, et al. 2012):

- honey bee group and other species group together (*ho*)
- honey bee group, other species group and wild bee species group together (*how*).

Considering only the wild pollinators, we take the other species group and the wild bee species group into account and combine them as a theoretical group (*ow*).

3.1.3 Almond weight

Klein, Hendrix, et al. (2015) investigated almonds harvested under four different treatments: a) normal water and nutrients b) reduced water/normal nutrients c) no nutrients/normal water d) reduced water and no nutrients. To each of these nutrient treatments, three different pollination treatments were applied: a) supplemental hand-pollination to maximise cross-pollination b) open-pollination with flowers exposed to bees freely foraging in the field and c) pollinator exclusion. The data set included 1,547 samples of weighted almonds for all treatment combinations.

We analysed these data about almond treatments and weights to determine the average weight of one almond. We determined the mean value for the weight over all treatment combinations to provide a robust average almond weight to later calculate the value (market price) of the developed almonds.

3.1.4 Almond market price

The almond market price was \$ 1.45 per pound in the year 2008 , in which the data on flower visits were collected.

3.2 Data upscaling and converting

Here, we upscale the data on flower visits from small-scale level to the overall pollination services during an entire season and for an entire tree and convert this pollination distribution into a farm income distribution. To this end, we determined the visitation frequency of each pollinator group per single flower in each management scenario. In a next step, we multiplied these visitation frequency by a factor of 4320 because the 20 s observation period of the data is 1/4320 of one typical almond season in which the almond flowers are open and insect pollinators forage: Almond flowering typically takes place between the end of February and mid-May, where one individual tree is flowering for two weeks (Soodan, Koul, and Wafai 1989). Here, we consider an almond tree flowering in the first two weeks of March. During this time there are on average 3.5 days of rain and 9 hours of sunshine per day (*Der internationale Klimaindex* 2015). Additionally, flowers open only between 10:00 a.m. and 12:00 p.m. (Soodan, Koul, and Wafai 1989). Further, honey bees forage only when wind speed is < 2.5 m s^{-1} and temperatures are above 12-13 °C. (Vicens and Bosch 2000 , Kevan and Baker 1983). That is, in the morning and the late afternoon, temperature is too low for honey bees to forage. Moreover, in March there are some windy days (Brittain, Kremen, and Klein 2013) so that in total one flower is open for approximately 6 hours in 4 days during that time in which honey bees will forage.

Then, we determined the probability of one representative flower to be visited at least once, so that pollination has probably taken place. Further, we assumed that pollination service follows a binomial distribution as pollination is discrete and to simplify, we assume pollination service to be independent of previous pollination services. For the binomial distribution we use the calculated probability of successful pollination for each combined pollinator group and the average number of flowers per almond tree as the sample size n, so we have three different distributions of pollination service per management scenario depending on the combined pollinator group.

We converted the given pollination distribution into the distribution of the farmer's income per tree and season. That is, we converted the number of successfully pollinated flowers, the number of almonds into the farmer's income by using the data about the average almond weight and the almond market price.

4 Results

4.1 Data Analysis

4.1.1 Flower visitors and observation frequencies

In the five different management scenarios, different compositions of flower visitors were observed. In scenario (a), organic orchards with a low percentage of surrounding natural habitat, Klein, Brittain, et al. (2012) observed 417 visits by honey bees, and 466 visits by the combined honey bee and other species group (*ho*). In scenario (b), organic orchards with a high percentage of surrounding natural habitat, Klein, Brittain, et al. (2012) observed 177 visits by honey bees, 391 visits by the combined group (*ho*) and 577 visits by all pollinators (*how*). In scenario (c), conventional orchards with low percentage of surrounding natural habitat, they observed 596 visits by the honey bee and 607 visits by all pollinators (*how*). In scenario (d), conventional orchards with a high percentage of surrounding natural habitat, Klein, Brittain, et al. (2012) observed 500 visits by the honey bee group, 747 visits by the combined honey bee and other species group (*ho*) and 931 visits by all pollinator groups together (*how*). In scenario (e), conventional orchards with a low percentage of surrounding natural habitat but with an adjacent strip of semi-natural vegetation along one orchard side, they observed 721 visits by the honey bee group, 838 visits by the combined honey bee and other species group and 851 visits by all pollinators (*how*). In scenario (a) and scenario (c), both of which with a low percentage of surrounding natural habitat, no visits by species of the wild bee species group were observed. Thus, there is no combination of the honey bee group, the other species group and the wild bee species group (*how*).

Over all, an increase in pollinator species diversity increases also flower visitation frequencies. That is, the wild pollinator species contribute to larger abundances concerning flower visitation frequencies.

4.1.2 Almond weight

Almond weight over all treatments was on average 1100.5 mg.

4.2 Income Distribution

The income distribution for each management scenario is depicted in Figure 1. In each scenario wild pollinators shift the probability distribution to higher income, whereas they enlarge the income range. The income range is from zero to 20 (scenario a) up to zero to 65 (scenario d). The income range is larger in scenarios in which wild bees occurred, whereas the type of farming (conventional/organic) does not lead to significant differences in the income distribution. Further, high numbers of wild pollinators have a large effect on the income distribution by increasing the expected income and by enlargening the income range, whereas small numbers of wild pollinators (e.g. "other species group" in scenario c)) only have a small effect.

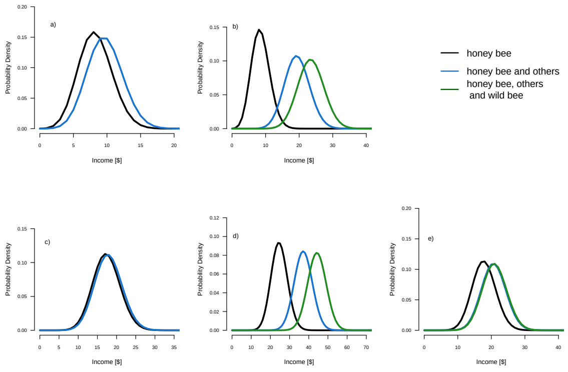

Figure 1: Income distribution of each management scenario due to pollination service by the different pollinator groups.

4.3 Statistical Numbers

In each scenario the expected income increases with higher pollinator diversity. However, also the standard deviation increases in each scenario due to higher levels of pollinator diversity. Further, the coefficient of variation decreases in each scenario with an increase in pollinator diversity. Each income distribution was right-skewed and shifted little towards a symmetrical distribution but still remained right-skewed by increasing the pollinator diversity. Table 1 shows the detailed results for each management scenario.

There are huge differences between the management scenarios regarding the expected income. In scenarios with low amounts of surrounding natural habitat and with no strip of semi-natural vegetation, no wild bee species occurred and thus, the expected income was low with \$ 5.12 to \$ 10.85. However, in scenario (e), conventional orchards with low amounts of surrounding natural habitat but with an adjacent strip of semi-natural vegetation expected income was similar (\$ 8.31 to \$ 9.56) to those orchards with low amounts of surrounding natural habitat. In contrast, the expected income of scenarios with high amounts of surrounding natural habitat was much higher (\$ 5.12 to \$ 31.40). The amount of the expected income here, is highly dependent on the level of pollinator diversity. For example, in scenario (d) the expected income increases by \$ 5.2 with additional wild bee species. Further, in scenario (b) the expected income increases by \$ 13.68 with the additional other species group.

The standard deviation increases with an increase in pollinator diversity. This effect is also larger in those scenarios, in which higher numbers of wild pollinators occur. However, the relative measure for variance, namely the coefficient of variation decreases with higher levels of pollinator diversity. That is, the increases in the expected income is larger than the increase in standard deviation an thus, the relative measure for variance decreases.

The skewness decreases slightly in each scenario with higher pollinator diversity. Still, each distribution remains right-skewed and the effect of the decrease in skewness is comparatively low.

Table 1: Results of the statistical moments of the income distribution due to different pollinator species diversity

management scenario	**(a)**			**(b)**			**(c)**			**(d)**			**(e)**		
	h	**ho**	**how**	**h**	**ho**	**how**	**h**	**ho**	**how**	**h**	**ho**	**how**	**h**	**ho**	**how**
$\mathcal{E}_v[y]\ [\$]$	5.12	5.99		5.12	18.80	22.80	10.55	10.85		17.50	26.38	31.40	8.31	9.45	9.56
$SD_v[y]\ [\$]$	1.97	2.07		2.68	3.64	3.83	2.75	2.77		3.59	3.98	4.06	2.36	2.45	2.45
$CV_v[y]$	0.38	0.35		0.33	0.19	0.17	0.26	0.26		0.21	0.15	0.13	0.29	0.26	0.26
$g_v[y]$	0.26	0.21		0.28	0.11	0.08	0.16	0.15		0.13	0.05	0.01	0.16	0.11	0.11

4.4 Risk premium and insurance value of wild pollinators in the different management scenarios

Risk premium and insurance value of wild pollinators highly differ depending on the exact type of risk preferences. For CRRA risk preference, the risk premium decreases with higher pollinator diversity resulting in a positive insurance value. In contrast, for both CARA and mean-variance risk preferences the risk premium increases with higher pollinator diversity, resulting in a negative insurance value (see Figure 2). Further, the insurance value increases for CRRA risk preferences with higher degrees of risk-aversion of the farmer, whereas the insurance value for CARA and mean-variance risk preferences decreases with higher degrees of the farmer's risk aversion.

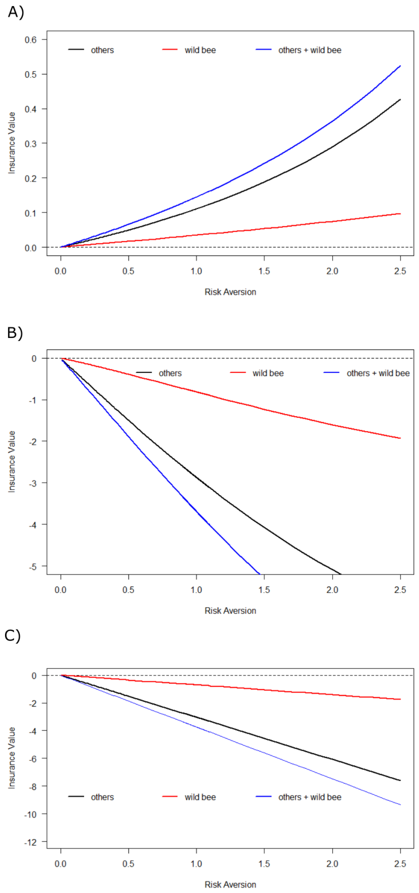

Figure 2: Insurance value of scenario b) with CRRA, CARA and mean-variance risk preferences (from top to bottom)

For the scenarios b) to e) the increase or decrease of the insurance value is monotonic. Interestingly, in scenario a) the insurance value does not monotonically increase or decrease (see Figure 3). For the CARA risk preference, the insurance value is negative with for $\rho < 0.09$, becomes zero for $\rho = 0.09$ and increases further to positive values with increasing degree of risk aversion. With CARA risk preferences there is also non-monotonic behaviour: When $\rho < 0.092$, the insurance value is negative and increases until $\rho = 0.092$ with an insurance value of -0.05 and decreases again. For the mean-variance preference there is again a linear decrease in the insurance value with higher degrees of risk aversion because the risk premium increases with higher pollinator diversity.

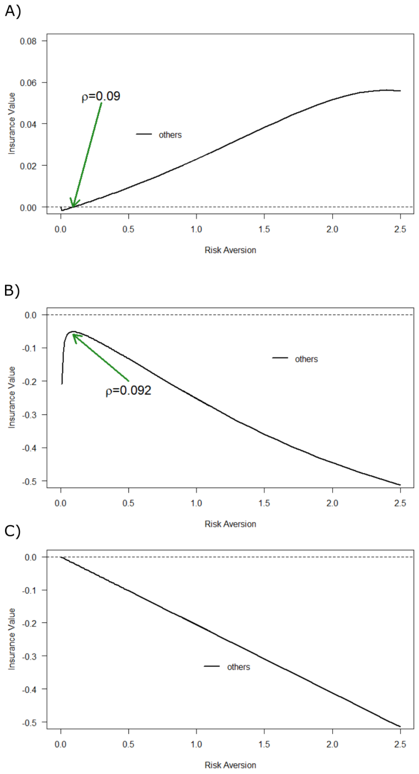

Figure 3: Insurance value of scenario a) with CRRA, CARA and mean-variance risk preferences (from top to bottom)

5 Discussion

The income distribution shifts towards higher incomes and incorporates a larger income range with an increase in pollinator diversity. Thus, the expected income and the standard deviation increases, whereas the coefficient of variation and the skewness decreases.

Further, the contribution of each pollinator group differs in each scenario. In the scenarios which had a high percentage of surrounding natural habitat the expected income increases stronger compared to scenarios which had low percentage of surrounding natural habitat due to the pollination services of diverse pollinators (Klein, Brittain, et al. 2012). That is, wild pollinators can contribute immensely to the farmer's income if there is a high percentage of surrounding natural or semi-natural habitat. Our results indicate that higher levels of biodiversity increase ecosystem service productivity. This confirms the hypothesis that a high level of biodiversity can augment ecosystem service productivity (Baumgärtner 2007), a result which was also reported for natural systems, inter alia, by Blaauw and Isaacs (2014) and Garibaldi et al. (2013). More diverse pollinator compositions extend the variance of the income distributions but their contributions to a larger expected income are so large that the relative variations decrease. Di Falco and Chavas (2009) also found that biodiversity (in terms of seed diversity) increase the variance of yield. For the relative variance, higher levels of pollinator diversity seem to have a stabilizing effect on the pollination services and thus, on the income. Similar findings have already been reported for wild bee species in highbush blueberry: wild bee richness was a good predictor for pollination services and the different pollinator species stabilized pollination services by responding differently to changing weather conditions (Rogers, Tarpy, and Burrack 2014). Thus, the effect on variance is ambiguous. The skewness of the distribution decreases with additional wild pollinating species. However, Di Falco and Chavas (2009) find an increase in skewness of yield due to higher levels of seed diversity. Nevertheless, also in this case each distribution is right-skewed and does not change to a symmetrical or left-skewed distribution. Thus, each income distribution has a high upside-risk.

For the risk premium and insurance value we find different trends depending on the exact type of the farmer's risk preferences. For the CRRA-preferences the insurance value is positive and increases in each scenario with an increase risk aversion. The farmer with this type of risk preference values the insurance by the wild pollinators positively. In contrast,the farmer with either a CARA- or a mean-variance preference values the same income distribution differently. Here, the insurance value is negative and decreases with increasing risk-aversion. That is, whether wild pollinating species increase or decrease the riskiness of the income lottery and thus, how the insurance value is perceived is dependent on the type of risk-preferences of the farmer.

Surprisingly, for both the CRRA- and the CARA-preferences the insurance value is not monotic with an increase in the degree of risk-aversion. The insurance value is then strongly depending on the degree of risk aversion and can even switch between positive and negative values.

6 Conclusion

Wild pollinating species have a positive mean effect on the farmer's income distribution. Further, they stabilize the income distribution, when taking the coefficient of variation into account. Whether wild pollinators also have an insurance effect is highly dependent on the exact type of risk preferences of the farmer.

References

Arrow, Kenneth Joseph (1965). *Aspects of the theory of risk-bearing.* Yrjö Jahnssonin Säätiö.

Baumgärtner, Stefan (2007). "The insurance value of biodiversity in the provision of ecosystem services". In: *Natural Resource Modeling* 20.1, pp. 87–127.

Baumgärtner, Stefan and Sebastian Strunz (2014). "The economic insurance value of ecosystem resilience". In: *Ecological economics* 101, pp. 21–32.

Binswanger, Hans P (1980). "Attitudes toward risk: Experimental measurement in rural India". In: *American journal of agricultural economics* 62.3, pp. 395–407.

Blaauw, Brett R. and Rufus Isaacs (2014). "Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependent crop". In: *Journal of Applied Ecology* 51.4, pp. 890–898.

Brittain, Claire, Claire Kremen, and Alexandra-Maria Klein (2013). "Biodiversity buffers pollination from changes in environmental conditions". In: *Global change biology* 19.2, pp. 540–547.

Crocker, T. D. et al. (2001). "Frontiers of Environmental Economics". In: *Frontiers of Environmental Economics.*

Delaplane, Keith S., Daniel R. Mayer, and Daniel F. Mayer (2000). *Crop pollination by bees.* Cabi.

Der internationale Klimaindex (2015). URL: `http://www.eklima.de/?d=klimadaten&s=Sacramento,%20California&o=&i=1439&z=USA%EF%BF%BD%EF%BF%BD%EF%BF%BDUSA` (visited on 03/04/2015).

Di Falco, Salvatore and Jean-Paul Chavas (2009). “On Crop Biodiversity, Risk Exposure, and Food Security in the Highlands of Ethiopia”. In: *American Journal of Agricultural Economics* 91.3, pp. 599–611.

Dillon, John L. and Pasquale L. Scandizzo (1978). “Risk Attitudes of Subsistence Farmers in Northeast Brazil: A Sampling Approach”. In: *American Journal of Agricultural Economics* 60.3, p. 425. DOI: `10.2307/1239939`.

Garibaldi, Lucas A. et al. (2013). “Wild pollinators enhance fruit set of crops regardless of honey bee abundance”. In: *Science (New York, N.Y.)* 339.6127, pp. 1608–1611.

Kevan, P. G. and H. G. Baker (1983). “Insects as flower visitors and pollinators”. In: *Annual review of entomology* 28.1, pp. 407–453.

Klein, Alexandra-Maria, C. Brittain, et al. (2012). “Wild pollination services to California almond rely on semi-natural habitat”. In: *Journal of Applied Ecology* 49.3, pp. 723–732.

Klein, A.-M., S. D. Hendrix, et al. (2015). “Interacting effects of pollination, water and nutrients on fruit tree performance”. In: *Plant Biology* 17.1, pp. 201–208.

Kreps, David M. (1990). *A course in microeconomic theory.* Harvester Wheatsheaf New York.

Pejchar, Liba and Harold A. Mooney (2009). “Invasive species, ecosystem services and human well-being”. In: *Trends in Ecology & Evolution* 24.9, pp. 497–504.

Pratt, John W. (1964). “Risk aversion in the small and in the large”. In: *Econometrica: Journal of the Econometric Society*, pp. 122–136.

Rogers, Shelley R., David R. Tarpy, and Hannah J. Burrack (2014). “Bee species diversity enhances productivity and stability in a perennial crop”. In: *PloS one* 9.5, e97307. ISSN: 1932-6203.

Soodan, A. S., A. K. Koul, and B. A. Wafai (1989). “Floral biology of almond (Prunus amygdalus L. Batsch) under cultivation in Kashmir valley”. In: *Proceedings: Plant Sciences* 99.3, pp. 297–300.

Varian, Hal R. and W. W. Norton (1992). *Microeconomic analysis.* Vol. 2. Norton New York.

Vicens, Narcís and Jordi Bosch (2000). “Weather-dependent pollinator activity in an apple orchard, with special reference to Osmia cornuta and Apis mellifera (Hymenoptera: Megachilidae and Apidae)”. In: *Environmental Entomology* 29.3, pp. 413–420.

Winfree, Rachael et al. (2007). “Native bees provide insurance against ongoing honey bee losses”. In: *Ecology letters* 10.11, pp. 1105–1113.