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Abstract.

We study insurance and productivity values associated with the Greek Gene Bank (GGB), the largest ex-situ conservation program in Greece. To evaluate the insurance value generated by the holdings of the GGB genetic resources, the current study examined scenarios for alternative arrival probabilities of an adverse event that will negatively affect production of seven major staple crops held at the GGB within the next 100 years. Productivity values were approximated through the probability of attaining increased yields by using the Bank’s genetic material. Our estimates suggest insurance and productivity values, which considerably exceed the costs of maintaining the GGB.

Key words: Gene bank, Valuation, Insurance value, Productivity value, Poisson arrival.

1. Introduction

Crop diversity stored and protected ex-situ by a gene bank offers valuable and diverse services. For a given crop, different varieties with differing characteristics and traits associated with specific properties such as resistance to cold, tolerance to drought, or resistance to diseases, represent a wealth of genetic potential. By combining different traits, experts and farmers have over the centuries enriched the variety of plants used to grow food and fodder, develop medicines and provide a number of other goods such as building materials or cloth. Thus there are values which emerge from the varieties preserved in the accessions[1] of a gene bank.

Within the "Total Value" framework the values generated by a gene bank can be broadly divided into two categories:

(i) Use values associated with the value of genetic resources in developing new foods or drugs. Using these genetic resources, breeders can develop new improved varieties with characteristics such as higher pest and disease resistance, resilience to climate change or increased productivity to enhance food production.

(ii) Non-use values which are related to bequest motives for conserving genetic material for the future.

In a recent survey, Smale and Hansen (2010) identify the following values associated with a gene bank:

1. The value of collections of genetic resources associated with their use to improve resistance of crops to disease and help enhance agricultural yields and mitigate the threat of economic problems in production of major food staples (e.g. developing wheat varieties with resistance to the Russian wheat aphid).
2. The value of plant genetic resources used to improve crop productivity.

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[1] An accession is a sample of planting material stored in an ex-situ collection of genetic resources. Accessions may or may not be unique and are not necessarily homogeneous.

3. The value of plant genetic resource accessions as a means to promote research on an international as well as a national level to support development of world agriculture.
4. The value of germ plasm flows from international repositories such as the centers of the Consultative Group on International Agricultural Research (CGIAR) and its International Agricultural Research Centers to benefit development of national research efforts.
5. The value of information relating to research using genetic resources to produce new goods such as new crop varieties or drugs. This information value has public good characteristics.
6. Direct and indirect value to farmers associated with direct distribution of genetic resource materials such as seeds to farmers.
7. Use of the gene bank materials collection to benefit vulnerable and subsistence-oriented agricultural communities as a means to combat poverty.

In terms of non-use values, there is also a general existence value stemming from preserving the varieties in all accessions of the gene bank for future generations.

The present paper presents an economic valuation of benefit flows associated with plant genetic resources conserved by the Greek Gene Bank (GGB), the largest ex-situ conservation program for plants in Greece. Two main types of benefits which are generated by the GGB, and which involve potential use of genetic resources for enhanced food security and increased productivity of agriculture, are analyzed by this study for a time horizon of 100 years. The first type of benefits corresponds to insurance values associated with providing insurance against events that might seriously harm commercial production, while the second type, relating to applications of genetic material to increase farm yields, corresponds to productivity values.

In this context we estimate emerging values associated with potential future contribution to secure and enhanced food production for seven major staple crops held at the GGB, namely wheat, cabbage, pulses (legumes), forage and pasture grasses (vetches), beets, grapes and tobacco.

Aggregate insurance values generated by the seven crops of interest held by the GGB were estimated within a range of alternative scenarios of agricultural risk and potential adverse shocks in their commercial production. Possible causes of a crisis in food availability can include extreme natural events such as droughts, disease or flooding, while agricultural production can also plunge due to human-induced causes such as political or financial crisis. As climate change is considered to pose significant new uncertainties for Mediterranean agriculture, the current study also serves to indicate the potential role of the GGB in mitigating the challenges of a changing climate. Overall the study indicates that for the seven crops of interest identified within the scope of this research, the GGB could, under alternative conditions, generate insurance values ranging from €55 to 995 million in present value terms.

Productivity values are also positive but lower than insurance values, ranging from €0.012 million for pulses to €5.57 million for sugar beets. It is worth noting, however, that in the design of scenarios for productivity values, conservative hypotheses concerning potential benefits of genetic material were adopted.

Finally, a cost benefit comparison based on the results of this study confirms that the benefits of the GGB, even with the conservative estimation adopted, significantly exceeds the costs of its operation. Thus in terms of insurance values generated by the GGB, the flow of annual equivalent values[2] was estimated to represent a minimum of €2.95 million whereas current operating costs of the GGB correspond to less than 3 per cent[3] of this amount on an annual basis. Hence this study suggests that maintaining and further developing the GGB is an economically justified strategy.

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[2] Annual equivalent is used in the sense that the present value of the annual flow equals the estimated aggregate insurance value.

[3] This is based on personal communication with officers of the GGB quoting costs currently on the order of €100,000 annually.

The remainder of the paper has the following structure. Section 2 provides a brief description of the GGB, section 3 present the valuation methodology, section 4 summarizes the results and section 5 concludes.

2. The Greek Gene Bank

Founded with support from the Food and Agriculture Organization (FAO) of the United Nations, the GGB is based in Thessaloniki Greece. Over the past 30 years it has banked about 12,000 samples of cultivated plants or their wild relatives, often no longer growing in fields or in nature.[4]

The GGB conserves plant germ plasm, the living tissue from which new plants can be grown, mostly in the form of seeds. The Bank is also designated to conserve a collection of grapevine species. Grapevine plants are grown as part of field collections maintained in Thessaloniki. Approximately half the collection consists of indigenous wild relatives of Greek crops while the other half are landraces of Greek origin or breeding materials of interest to scientists.

Some crops in the collection have a very long history in farming, spanning thousands of years of active cultivation in the region. Additionally the Bank collection includes some rare, vulnerable or endangered species, such as for example *Medicago scutellata, Astragalus peregrinus* ssp. *Peregrine.* For some crops for which Greece is said to be the geographical center of origin, the Bank holds particularly large stocks of genetic material. The current study focuses on a series of crops for which the GGB collection is particularly rich on a world level and which are therefore of particular interest to researchers. Among the regional crops banked, the collection of wild wheat relatives, legumes and grapes are of great

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[4] Information on parts of the GGB collection is available through an online inventorying database containing European plant genetic resources of interest to researchers. The EURISCO Catalogue on National Inventories (NIs) of plant genetic data is available at: http://eurisco.ecpgr.org/home_page.html

importance. Sustained plant breeding over centuries, together with a naturally diverse environment, has resulted in high crop diversity in these staple crops.[5]

Regarding the crops of interest for this study, the GGB holds: more than 600 wheat accessions, more than 320 grasses accessions, and a great variability of of grain legume landraces. It also holds more than 280 accessions of Brassica landraces, over 800 accessions of Beta genetic resources, 270 grapevine cultivars of which 202 are very rare autochthonous landraces, and more than 480 accessions of N. tabacum.

3. Values Generated by the Greek Gene Bank: Valuation Methodology

In order to provide quantitative approximations of the value of the Greek Gene Bank based on market data which may yield relatively more reliable estimates, the present study focuses on two particular types of values associated with the accessions of a gene bank: insurance value and productivity value.

Although other types of values mentioned in the introduction could be quantitatively important, we do not attempt to estimate them empirically in this study because of the considerable uncertainties involved and the lack of appropriate data. In any case we believe that insurance and productivity are two major sources of value generated by gene banks, which can be approximated in a meaningful way from existing data.[6] If the GGB can be justified economically through the insurance and the productivity values only, it is clear that the other sources of value can further support it.

To measure insurance and productivity values, we first develop a conceptual framework based on the expected value of benefits generated when a gene bank accession is used in the future to provide a novel variety after a destructive event, or to enhance the productivity of an

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[5] Table A1 in the Appendix presents the plant genetic resources of the GGB.

[6] For example, Zohrabian et al. (2003) is the only attempt to measure the marginal value of an accession. They found that the expected marginal benefit from exploring an additional unimproved gene bank accession in breeding resistant varieties of soybean more than covered the costs of acquiring and conserving it.

existing variety.

3.1 Insurance Value

Valuation studies undertaken indicate that crop diversity can be an important factor, in economic terms, in ensuring food security. Crop wild relatives for instance are known for their high potential to provide disease resistance because they have closely existed with pathogens with which they have reached fine biological balances.[7]

To model the insurance value generated by a gene bank we consider the case where the occurrence of a set of undesirable events in the future will damage the value of production of an existing commercial variety. Examples of such events could be pest outbreaks, diseases, reduced precipitation, heat waves, or extreme weather events. The assumption is that a specific accession of the gene bank could be used to develop substitutes for the affected variety and at least partially recover the lost production value. We will call the event or combination of events that will cause the production loss of an existing variety and that will create the need to employ resources of the gene bank the *triggering event.*

3.1.1 Modeling the arrival of the triggering event

The usual approach for modeling the arrival of stochastic events is the use of the Poisson process. We start by assuming that the arrival of triggering events follows a homogeneous Poisson process $N(t)$ with rate (or intensity) λ. The arrival of the undesired events can be defined, using the Poisson process, as:

$$\Pr\left[N(t+\tau)-N(t)=k\right]=p(k)=\frac{e^{-\lambda\tau}(\lambda\tau)^k}{k!}, k=0,1,... \tag{1}$$

where $(N(t+\tau)-N(t))=k$ is the number of events in the time interval $(t,t+\tau]$. Thus equation (1) provides the probability that between time t and time $t+\tau$ the undesirable

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[7] Wild relatives are estimated to have contributed approximately US$ 340 million per year, through yield and disease resistance, during the period 1976-1980, to the farm economy of the United States (Shand, 1997).

events will occur k times, where λ is the expected number of occurrences of the events between time t and time $t+\tau$. For example, if we are at the present time $t=0$, and we expect in the next decade 15 undesirable events and that for the reduction in productivity of a given variety 20 events are required, then $\lambda=15, k=20$ and the probability of having the twenty events, regarding the decade as the unit of time, is 4.18 per cent. In this type of modeling, there are two issues that should be further addressed.

The first is that given the uncertainty and the complexity about the nature and the timing of the arrival of the events that will eventually trigger the use of the gene bank, we consider - in order to make practical approximations possible - only one triggering stochastic event. This event could be regarded as a "threshold", which occurs after the occurrences of other related events (e.g. increase in the number of hot days in the summer, reduced precipitation) and leads to severe damages in the commercial value of the variety's production. To put it differently, the triggering event could be the manifestation of a composition of different stochastic shocks associated with climate change or other external drivers. This threshold event will trigger the use of the gene bank for the provision of substitute or improved varieties. Avoiding losses associated with a sudden shock in the supply of food represents a reflection of the value of insurance offered by the gene bank. The recovery of the expected commercial value obtained through the use of the gene bank reflects the insurance value of the gene bank for this specific variety.

The second issue is that since climate change is expected to increase the number of undesirable events for agriculture, a non-homogeneous Poisson process where the rate λ is an increasing function of time could be a better way of modeling. Thus we model the arrival of the triggering event that will stimulate research to engineer new plants using the collection of the gene bank, with the help of the cumulative distribution function of a gamma distribution which is defined as:

$$g\left(t;\alpha,\beta\right)=\beta^{\alpha}\frac{1}{\Gamma\left(\alpha\right)}t^{\alpha-1}\,\mathrm{e}^{-\beta t},t\geq 0,\alpha,\beta>0,\Gamma\left(\alpha\right)=\left(a-1\right)!$$

where α is the shape parameter and β is the rate parameter.

The cumulative distribution function is defined as

$$F\left(t;\alpha,\beta\right)=\int_0^t g\left(\tau;\alpha,\beta\right)d\tau=\frac{\gamma\left(\alpha,\beta t\right)}{\Gamma\left(\alpha\right)}$$

where $\gamma\left(\alpha,\beta t\right)$ is the lower incomplete gamma function, $\gamma\left(\alpha,\beta t\right)=\int_0^{\beta t}u^{\alpha-1}\,\mathrm{e}^{-u}\,du$. Let $m\left(t\right)=F\left(t;\alpha,\beta\right)$. Since $0\leq m\left(t\right)\leq 1$ for all t, if there exists an $m\left(t_0\right)\approx 1$, we will interpret t_0 as the time at which the expected triggering event will arrive.

The triggering event is however stochastic. We model the probability of arrival of this single composite event by a non-homogeneous Poisson process. In general a non-homogeneous Poisson process provides the probability that $N\left(t\right)$ events will arrive at time t, and is defined as:

$$\Pr\left(N\left(t\right)=k\right)=p\left(t,k\right)=\frac{m\left(t\right)^{k}\,\mathrm{e}^{-m(t)}}{k!} \tag{2}$$

where $N(t)=k$ is the number of events by time t and $m\left(t\right)=\int_0^t\lambda\left(u\right)du$ is the mean occurrences up to time t, with $\lambda\left(u\right)$ being the number of expected occurrences at time u. The number of events in the interval $\left(t,t+\tau\right]$ which is $N\left(t+\tau\right)-N\left(t\right)$ is a Poisson random variable with rate $m\left(t+\tau\right)-m\left(t\right)$.

In our case, we are considering a single composite triggering event. Therefore $k=1$ and

$$\Pr\left(N\left(t\right)=1\right)=p\left(t,1\right)=m\left(t\right)\mathrm{e}^{-m\left(t\right)} \tag{3}$$

is the probability that the triggering event will arrive at time t.

It should be noted that since $0\leq m\left(t\right)=\int_0^t\lambda\left(u\right)du\leq 1$, $m\left(t\right)$ can be interpreted as the fraction of the events that constitute the composite triggering event which have occurred up to time *t*. The triggering event will emerge at t_0 if $m(t_0) \to 1$. Figure 1 presents the function $m(t) = F(t;10,2)$.[8]

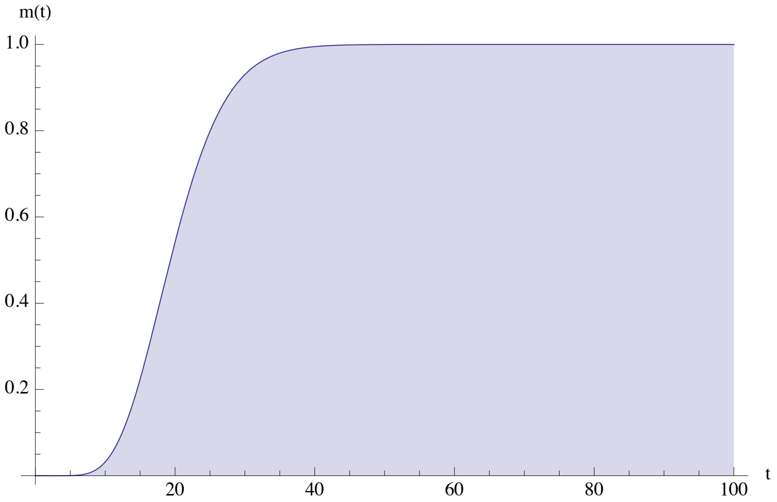

Figure 1. The expected arrival of the triggering event

The value $m(20) = 0.542070$ can be interpreted as indicating that 20 time periods from now it is expected that 54.21 per cent of the events leading to the triggering event will occur. The value $m(45) = 99.89$ implies that it is expected that the triggering event will occur 45 time periods from now.

The arrival probability of the triggering event at any point of time $t \in [0,T]$ is given by $p(t,1) = m(t)\mathrm{e}^{-m(t)}$ and is shown in Figure 2.

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[8] All calculations and simulations were conducted using the software Wolfram Mathematica 8.

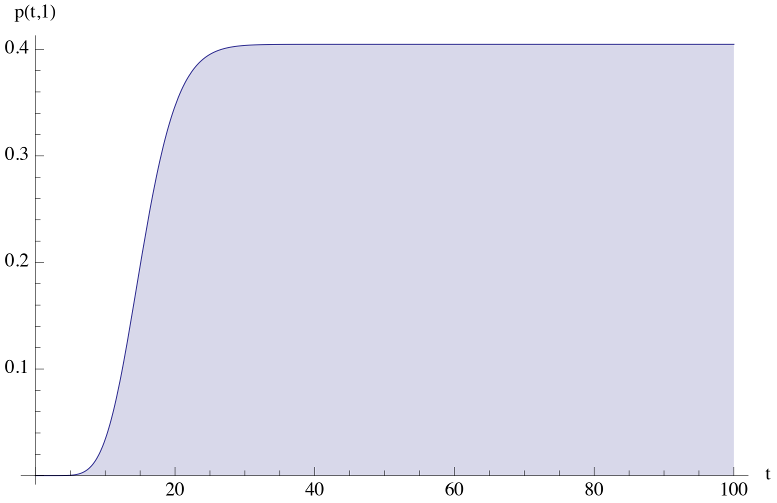

Figure 2. Arrival probabilities for the triggering event

As Figure 2 shows, the probability of having the triggering event early is low. For example, *p*(10,1)=0.0339, implying that the probability of having the triggering event 10 years from now is 3.4 per cent. On the other hand, *p*(45,1)=0.4046, suggesting that the probability of having the triggering event 45 years from now, is 40.46 per cent and remains approximately constant after that. Thus after year 45 we expect the triggering event with an approximately 40% probability.

3.1.2 Insurance value estimation

Assume that the flow of the value of agricultural production lost due to the triggering event is $R_{t,t+\tau}, t, \tau = 0,1,2....$ where t is the time when the event occurs. Under the simplifying assumption that the triggering event is totally destructive, $R_{t,t+\tau}$ is the flow of the commercial value of the agricultural production of the given variety. Thus $R_{4,9}$ is the loss five periods after the event which took place at $t = 4$. The probability of the triggering event occurring at time *t* is given by the non-homogeneous Poisson process $p(t,1)$ defined in (3).

Once the event occurs, the recovery will not be instantaneous because there is a time lag between the triggering event and the development by the gene bank of substitute varieties that can successfully replace commercial production, due mainly to technical reasons. For the purposes of the conceptual model we assume there is a delay period of length d for the breeding of a novel variety, after which there is another delay of length d' until the new variety becomes fully operational as a substitute for the damaged variety.

Let $V_t = \sum_{\tau=0}^{T} \frac{R_{t,t+\tau}}{(1+r)^{t+\tau}}$ be the present value now of losing at time *t* the commercial value of a variety due to the arrival of the triggering event at time *t.* These losses correspond to the annual losses of agricultural production of the commercial variety from the time of the triggering event, until some sufficiently large time *T.* This time denotes the time horizon over which the affected variety would have been productive, if the triggering event had not emerged.

Assume: (i) a delay $d+d'$ until the novel variety becomes fully commercially operational, $h = d + d'$; (ii) C_h development costs until the novel variety becomes fully operational; (iii) linear recovery of the commercial value during d'; and (iv) in order to simplify notation without influencing robustness of the exercise, a constant annual flow *R* for the commercial value of the agricultural production. Then the present value of the recovered commercial production if the triggering event occurs at time *t* will be:

$$RV_t = \frac{\theta}{(1+i)^{t+d}} \left[\frac{1}{d'} R + \frac{1}{(1+i)} \frac{2}{d'} R + \ldots + \frac{1}{(1+i)^{d'-1}} \frac{d'-1}{d'} R + \sum_{\tau=0}^{T-d'} \frac{R}{(1+i)^{\tau+d'-1}} \right] - \sum_{h=0}^{d+d'} \frac{C_h}{(1+i)^{t+h}} \quad (4)$$

where $0 < \theta \leq 1$ is a recovery coefficient. If $\theta = 1$, the new variety provides full recovery for the damaged variety. The recovery coefficient can also be interpreted as the proportion of the total commercial value affected by the triggering event. For example, $\theta = 0.5$ means that only 50 per cent of the commercial value is affected by the triggering event. Of course the recovery coefficient can be interpreted as a combination of the proportion of recovery and the proportion of affected value.

To transform this recovered value into an insurance value, the present values should be weighted by the probability that the triggering event will occur at time *t.* The sequence

$$p(0,1)RV_0\,, p(1,1)RV_1\,, p(2,1)RV_2\,, \ldots, p(\tau,1)RV_\tau\,, \ldots \tag{5}$$

denotes the expected present value of the accession in terms of the sum of values of agricultural output recovered by using gene bank resources after adverse events in the supply of food at different points in time.

Therefore each specific term of the sequence indicates, in present value terms, the insurance value of the gene bank with respect to the specific variety at each point of time. Thus $p(2,1)RV_2$ is the insurance value of the gene bank at $t=2$. The insurance value of the gene bank increases with the probability of occurrence $p(t,1)$.

We denote each element of the collection of the expected present values (5) by

$$\left\{EV(0), EV(1), \ldots, EV(\tau), \ldots\right\}. \tag{6}$$

and define as the insurance value (*IV*) of the gene bank with respect to the specific variety, the maximum element of (6), or:

$$IV = \max\left\{EV(0), EV(1), \ldots, EV(\tau), \ldots\right\}. \tag{7}$$

The value of the gene bank for the specific variety is therefore the maximum expected value of the commercial agricultural production, which is expected to be recovered by using the accession of the gene bank, if a destructive stochastic event occurs in the future.

3.2 Productivity Value

Conservation of crop diversity by gene banks can play a key role in helping breed improved agricultural varieties to bridge the yield gap and to meet future global needs for food. Food production has increased dramatically over the past century. Breeding of improved crop varieties with higher yields played a central role in increasing outputs, which also rose as a result of the use of fertilizers, herbicides, pesticides, and mechanization. As much as 20-40 per cent of increased yields between 1945 and 1990 are estimated to be attributed to plant breeding (Pimentel et al., 1997).

In the future, an increase in agricultural yields will continue to be necessary. Just satisfying the expected food and feed demand will require a 70 percent increase in global food production by 2050, according to projections by the Food and Agriculture Organization. Additionally, new crop varieties will need to help decrease pressure on the environment by being less demanding in terms of water and soil nutrients while being adapted to a changing climate.

The productivity value emerges through breeding of new improved crop varieties with beneficial traits from the genetic pool of the bank that increase productivity of yields. To value the accession in terms of productivity value, we follow the approach developed by Simpson et al. (1996) for valuing potential discoveries from genetic resources collections in the pharmaceutical industry.[9]

Consider an accession of genetic resources with n contents, and assume that, with the existing technological knowledge, any material of the accession, which is randomly sampled, may increase the productivity of an existing commercial variety or may yield a new commercial variety after appropriate R&D and product development costs. Let the probability of success when the first variety is sampled be $x(t)$. Each new sampling is treated as a new Bernoulli trial with equal probability of success. Thus if the first trial is not successful, the probability of success in the second trial is $(1-x(t))$, the probability of success in the third trial if the second is unsuccessful is $(1-x(t))^2$, and so on until the whole accession is sampled. When a success occurs, the research activity for this collection is completed. We assume that the probability of success in the first trial is dependent on time to indicate that the success probability may increase due to increased knowledge generated during the process of the R&D activity.

Let $z(t+\tau)$, $t,\tau = 0,1,2,...$ be the annual flow of benefits realized from a productivity

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[9] See also Rausser and Small (2000) for the use of research leads in bioprospecting.

enhancement if the success after n trials occurs at time $t=0,1,\ldots$, and let $\frac{W(t)}{(1+i)^{t+d}}$ be the present value of the annual benefit flow $z(t+\tau)$ in terms of agricultural value from the productivity enhancement or the new commercial variety, when there is a delay of *d* years between the success and the commercial development of the more productive variety. Let also c_t be the present value of the cost associated with R&D and product development costs for the productivity enhancing development.

The productivity value of the accession of *n* varieties at time *t* will be:

$$\begin{aligned} &PV_t(n) = x(t)W(t) - c_t + (1-x(t))(x(t)W(t)-c_t) + \\ &(1-x(t))^2(x(t)W(t)-c_t) + \ldots + (1-x(t))^{n-1}(pW(t)-c_t) = \\ &= \frac{x(t)W(t)-c_t}{x(t)}\left[1-(1-x(t))^n\right] \end{aligned} \tag{8}$$

We define as the productivity value *PV* of the collection the maximum of (8) with respect to time *t*, or

$$PV = \text{argmax}_t \; PV_t(n). \tag{9}$$

4. Valuation of the Greek Gene Bank

We apply the methodology developed in the previous section to seven crop varieties that constitute crops of interest within the collection of the Greek Gene Bank. The crops selected are wheat, tobacco, pulses, white cabbage, vetches, grapes, and sugar beets.

4.1 Insurance Value

To apply the methodology regarding the insurance values stemming from the Greek Gene Bank, we need two types of information: (i) information about the arrival of the triggering event, and (ii) information about the value of the agricultural production affected by the adverse event.

4.1.1 The triggering event

Food genetic resources are expected to play an important role in helping to develop new crop varieties with climate resistant characteristics to counter adverse impacts of climate change on agriculture. Wheat is regarded as the most sensitive product to climate change. A recent study by the Bank of Greece (2011) estimates the impact of climate change in Greece on agriculture to include more than 10 per cent losses in wheat production in big regions of Greece during 2041-2051. The same study estimates reductions in grape production at around 10 per cent during 2091-2100 in southern Greece and the islands. The GGB keeps accessions related to wheat and grapes.

Similar indications are provided by Skuras and Psaltopoulos (2012) for the Mediterranean area. They state, following Iglesias et al. (2007), that the main risks to agricultural production imposed by climate change in Europe result from changes in factors such as: (1) Water resources and irrigation requirements; (2) Soil fertility, salinity and erosion; (3) Crop growth conditions, crop productivity and crop distribution; (4) Land use; (5) Optimal conditions for livestock production; (6) Agricultural pests and diseases; and (7) Increased expenditure on emergency and remediation actions.

In addition, Skuras and Psaltopoulos (2012) indicate that climate change and the associated higher air temperatures will create conditions suitable for the invasion of weed, pest and diseases adapted to warmer climatic conditions. Alcamo et al. (2007) argue that increasing temperatures may also increase the risk of livestock diseases by supporting the dispersal of insects, enhancing the survival of viruses from one year to the next, and improving conditions for new insect vectors that are now limited by colder temperatures.

This evidence suggests that climate change is likely to induce a triggering event that may necessitate the use of gene banks to recover, at least partly, lost production. However given the uncertainties involved, it seems that point estimates of the arrival of this event will not be very useful. Thus we decided to build a scenario analysis to evaluate the insurance value for a range of alternative hypotheses at varying points in time and for various probabilities of arrival of the adverse event. In particular we examined nine scenarios with arrival of the event in $Y=\{45,60,80\}$ years in the future, and probability of arrival at the specific year $P=\{0.1,0.2,0.4\}$. Combining by using $Y\otimes P$ derives nine scenarios which may be regarded as capturing both optimistic expectations (that is, the triggering event will arrive 80 years from now with a probability of 10 per cent) and pessimistic expectations (that is, the triggering event is will arrive 45 years from now with a probability of 40 per cent). Optimistic expectations are associated with low insurance values, while pessimistic expectations are associated with high insurance values.

4.1.2 The value of affected production

To approximate the value of potential lost production due to the triggering event, we use the value of agricultural production of each variety as a base. We use time series data on values of production, in constant 2005 euros, and cultivated areas between 1990-2006 obtained by the Hellenic Statistical Authority (ELSTAT).[10] The names that the GGB uses for the varieties held and the corresponding accessions do not fully correspond to the names used by ELSTAT. The varieties of the empirical application using the ELSTAT names, with the general variety name used by the GGB in parentheses, are: Total wheat (soft and hard wheat); Tobacco, all varieties; White cabbage (Brassica); Pulses (grain legumes); Vetches (forage and pasture crops); Grapes; Sugar beets.[11]

We assume that the future flow of production in the absence of any external event would be the average 1990-2006. This is a working assumption since future policy and institutional changes in the EU might produce major changes in the structure of production.

4.1.3 Time to develop the new variety

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[10] http://www.statistics.gr/portal/page/portal/ESYE

[11] For all practical purposes the ELSTAT name and data correspond to a subset of the accessions of the variety.

We assume that the delay between the triggering event and the development of the new variety will be 10 years and that another 5 years will pass until the new variety becomes fully commercially operational. The factors and costs shaping the capacity of a gene bank to help recovery of agricultural production are briefly presented below.

Restoring food security following a major adverse event can be aided significantly by having a wide pool of agricultural plant genetic resources to re-introduce or engineer new plant stocks. For the purposes of this exercise, we will group triggers of a food crisis into two general types of events: disease and non-disease causes of a shock to food supply.

The ability of a gene bank to breed disease resistant crops will vary depending on whether genetic material that can confer resistance is found within its stock. The larger the genetic pool a bank conserves, the bigger the probability that traits with desired properties will be identified.

Even if a desired trait is located by experts, the breeding of a novel variety requires periods of time that can stretch to 12 years[12] using modern breeding technologies. However, the time needed has decreased: use of molecular markers techniques allows breeders to monitor progress in conferring desired traits into a new variety more effectively, thus leading to an approximate decrease of 5 years in the time needed to engineer a crop today as compared to a couple of decades ago.

A shock in food security can result from causes other than disease, such as conflict leading to a breakdown in seed supply, disruption in farming and sharp decrease in agriculture's ability to produce food. In case of a major rupture in agricultural and seed production, the ability to restore farming can depend on having a critical mass of seed material, which can be used to generate new stocks. In this case the role of a gene bank can be valuable in offering an initial stock of seeds and expanding seed supplies to meet growers'

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[12] This is based on personal communication with officers of the GGB.

needs. The time period needed to re-develop seed stock to restore agricultural activity can extend to about five years.

Local gene banks can help to sustain food security through providing human expertise needed to convert existing genetic resources into new stocks of agricultural products. Experts at a national gene bank who are familiar with local crop varieties are more capable of screening through extensive amounts of genetic information to pick necessary material for development of disease resistant crops. Similarly, faced with a shortage in seed supply, local staff is in a better position to grow seed to meet targets for recovery of production. Therefore there is an intrinsic value to having a local gene bank that stems from having the resources, both genes and experts, needed to convert resources into solutions for sustained food security. This advantage can also be seen in terms of lowering the amounts of time needed for a gene bank to respond to crisis and provide ways of setting agricultural activity back on track.

Breeding new varieties to overcome agricultural shocks also entails costs. In a recent study on the economic value of coffee genetic resources, Hein and Gatzweiler (2006) find that costs of breeding programs range from US$ 300,000 (Van der Vossen and Walyaro, 1980) to 2 million per year (Bertrand, 2005; Van der Vossen, 2005) for programs involving collaboration of multiple research institutes and use of modern biotechnological tools.

4.1.4 The choice of the discount rate

Policy makers need access to information concerning the discount rate of various future choices in order to make decisions concerning policy, including environmental policy. Yet the choice of the proper discount rate for calculating present values is an open issue in economic theory. Stavins (2005) notes that the choice of the discount rate to be employed in the valuation of future costs and benefits can be difficult, particularly where impacts are spread across a large number of years involving more than a single generation. There is evidence from market behavior and from experimental economics indicating that individuals may employ lower discount rates for impacts of larger magnitude, higher discount rates for gains than for losses, and rates that decline with the time span being considered. This supports the idea of using discount rates which decline over time; however this approach may face time inconsistency problems.

The discount rate discussion is beyond the scope of the present study. In our calculations we use a 5 per cent discount rate in real terms. This value is suggested by the European Commission (EC, 2008) as a benchmark real financial discount rate. We choose to use a financial discount rate of 5 per cent since we estimate insurance and productivity values in the context of financial analysis using market data. It should be noted that use of more complicated discount structures with declining discount rates would not change the qualitative characteristics of our results.

Table 1 presents the estimated expected insurance values for the seven crops of interest contained within the collection of the GGB.

Table 1. Expected insurance value (million €)

Crops	Year of Triggering Event	Probability of Triggering Event		
		10%	20%	40%
Wheat	45	58.75	119.64	235.00
	60	22.01	44.82	88.04
	80	13.57	27.63	54.27
Tobacco	45	43.09	87.76	172.38
	60	16.14	32.87	64.57
	80	9.95	20.67	39.81
White Cabbage	45	10.27	20.93	41.11
	60	3.85	7.85	15.40
	80	2.37	4.83	9.49
Pulses	45	12.66	25.78	50.65
	60	4.74	9.66	18.97
	80	2.92	5.95	11.70
Vetches	45	40.40	80.27	161.60
	60	15.13	30.82	60.54
	80	9.33	19	37.32
Grapes	45	60.49	123.19	241.99
	60	22.66	46.15	90.65
	80	13.97	28.45	55.89
Sugar beets	45	23.17	47.20	92.70
	60	8.68	17.68	89.11
	80	5.35	10.90	21.41

Figure 3 provides a graphical presentation of the insurance value surface for wheat.

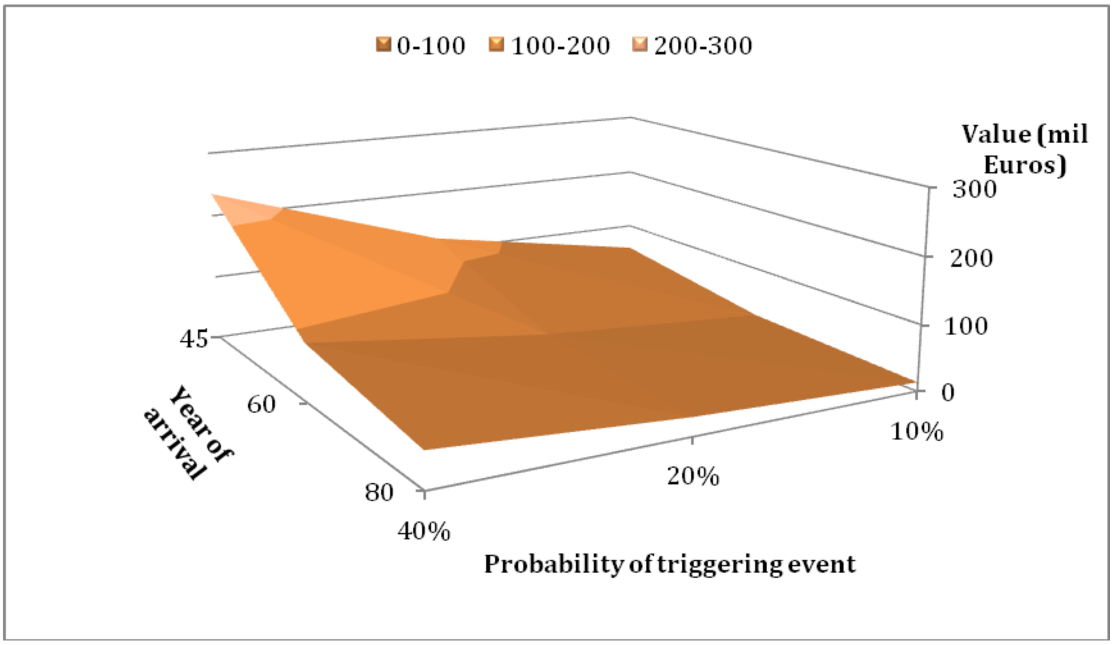

Figure 3. Insurance value surface: wheat

The surface indicates that the insurance value attains its largest value at the pessimistic scenario (year of arrival of the triggering event 45, probability of arrival 40 per cent), and its lowest value at the optimistic scenario (year of arrival of the triggering event 80, probability of arrival 10 per cent). The whole surface can be regarded as a piecewise approximation of the insurance value that the GGB provides by helping to develop improved varieties to counter shocks in food production, plotted against a range of years and probabilities of occurrence. The insurance surface for the rest of the varieties has a similar shape, structure and interpretation.

Changes in our basic assumptions about the values of the parameters will shift the surface either upwards, increasing the insurance value, or downwards, reducing the insurance value. Therefore:

- A reduction in the discount rate will uniformly increase insurance values for all accessions and vice versa.

- An increase in the probability of arrival of the triggering event for any given year will uniformly increase insurance values for all accessions and vice versa.
- A longer delay in arrival of the triggering event for any given arrival probability will uniformly reduce insurance values for all accessions and vice versa.
- A reduction in the recovery parameter θ, or in the value of the affected production, will uniformly reduce insurance values for all accessions and vice versa.
- An increase in the time required to provide a new variety once the triggering event arrives will uniformly reduce insurance values for all accessions and vice versa.

It should be noted that since the cost of developing the new variety when a triggering events arrives has not been accounted for, these values should be considered gross expected insurance values.

On the other hand a very simple benefit-cost rule would indicate that the operation of the GGB can be justified if costs associated with maintaining the GGB are lower than the insurance value offered by the Bank. The present study estimates that the insurance values offered by seven crops of interest held by the Bank range from €55 million under the optimistic scenario to €995 million under the pessimistic scenario, in present value terms.

The equivalent annual value, at a 5 per cent discount rate, is €2.95 million for the pessimistic case and €54.5 million for the optimistic case (values, in present value terms, are in constant 2005 euros).

4.2 Productivity Value

To apply the methodology regarding the productivity values stemming from the GGB, we need two types of information: the increase in productivity of a specific variety due to the R&D activities of the GGB, and the probability of success in developing crops with increased productivity after the first trial in the research process.

Regarding the first type of information, we consider a uniform 10 per cent increase in average production (1995-2006) per stremma (1000 m^2) for all varieties. The increased production was valued at the corresponding average prices in constant 2005 euros for the same period. The choice of 10 per cent is arbitrary and reflects a preference for the conservative hypothesis concerning potential benefits of genetic material. For instance, research efforts of the Greek Cereal Institute in the 1980s resulted in improved yield varieties which led to an increase in productivity of about 20 per cent. Furthermore, improvement of wheat varieties by the Greek Cereal Institute led to an approximately threefold increase in national wheat production over the period 1930-1970, enabling increased needs for this basic bread crop to be met successfully.

The probability of success was set at 0.0000129 which is the value used by Simpson et al. (1996), while the R&D cost was set at a level that allowed the productivity enhancement process to be profitable, the implicit assumption being that if the process is not profitable at market prices, no R&D activity will be undertaken. The productivity value was also estimated for three additional success probabilities: 0.000028, 0.000064, and 0.00011, and for the number of accessions held for each of the analyzed varieties held by the GGB.

Figure 4 relates the increase in the value in agricultural production following a successful development of an improved variety, with values of success probabilities in the first trial for wheat.

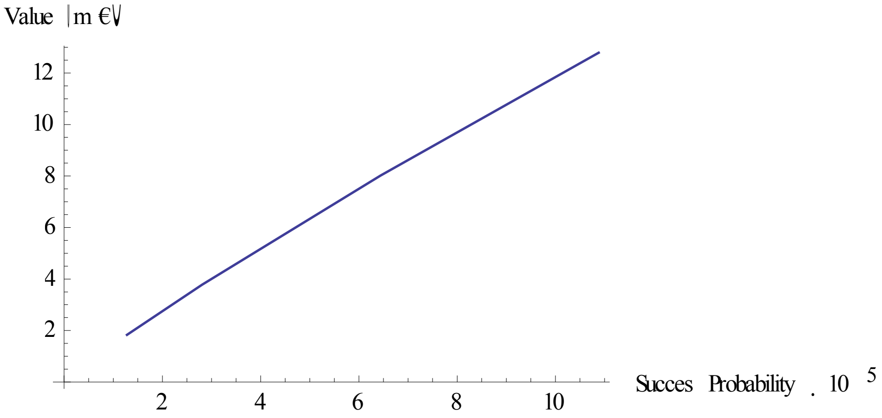

Figure 4. Wheat

As expected productivity values increase with the success probability. Furthermore:

- An increase in the attained productivity enhancement from the initial choice of 10 per cent will shift the value curves upwards and vice versa.
- An increase in the number of accessions for the specific variety will shift the value curves upwards and vice versa.
- An increase in the cost of R&D will shift the value curves downwards and vice versa.

The graphs for the rest of the varieties have a similar shape, structure and interpretation. The overall picture is that, under conservative assumptions, the GGB can generate positive net productivity values. In the "worst case" where the success probability in the first sampling takes its lowest value of 0.0000129, the productivity value ranges from a minimum of €0.012 million for pulses to a maximum of €10.13 million for vetches. These "minimum productivity values" for the seven commercial varieties, which correspond to the GGB accessions, are shown in Table 2.

Table 2. Minimum productivity values

Commercial variety	Productivity value (million €)
Wheat	1.83
Tobacco	0.23
Pulses	0.012
White Cabbage	0.303
Vetches	10.13
Grapes	1.22
Sugar Beets	5.57

These values provide some indication of the areas toward which R&D aiming at enhancing productivity should be directed.

5. Concluding Remarks

As noted in the introduction, values associated with the Greek Gene Bank could include other non-market based values in addition to the insurance and productivity values. These values are hard to estimate since direct markets for the services provided by ex-situ conservation through a gene bank are missing. On the other hand, intuition and common sense suggest that these values exist and could be large. Drucker et al. (2005) put forward an argument which suggests that since the costs of ex-situ conservation (gene banks) is relatively easy to calculate and it seems "… to be lower than any sensible lower-bound estimate of benefits, undertaking the expensive and challenging exercise of benefits estimation is not necessary."

In this study we did not take this point of view, not only because this is the first attempt to assign values to the GGB and therefore to set some kind of a value benchmark, but also because, at least for insurance and productivity, we feel that by using market data we can obtain a good approximation of these values. We think that the discipline provided by market data is a good basis for providing reliable estimates. Although the values emerging from this study are also subject to uncertainties, we feel that the methodology that was developed, combined with sensitivity analysis, provides an approximation, at least in the first order, of the true underlying values.

Given that climate change in Greece is likely to trigger events through which the insurance value of the GGB will be realized, while knowledge accumulation might induce productivity enhancements, the values estimated by this study can be regarded as an indication of the values associated with the Greek Gene Bank. It should be understood however that a triggering event or a productivity breakthrough, should they occur, would be associated not with all but with some of the accessions held by the GGB. Therefore the estimated values should be understood as providing a range of the values emerging from the GGB. These values could be further increased, even by small amounts, if we also account for the wider set of values associated with the GGB. Finally comparison of annual equivalent values generated by the GGB with corresponding operating costs, makes clear that maintaining and further developing the GGB is an economically justified strategy.

There are many challenges facing gene banks. Apart from collection, proper documentation, evaluation and maintenance are also required (Wright, 1997), while according to the Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture (FAO, 2010), gene bank collections are still at risk. With regard to the Greek Gene Bank, the major challenges are continuation of collection, regeneration of aging stocks, documentation, evaluation and maintenance of facilities. The results of this study provide insights into values generated by the GGB, which even though they represent a subset of all the possible values generated by a gene bank, are sufficient to establish its importance.

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Appendix

Table A1. Plant genetic resources of the Greek Gene Bank

Genus	**Common name**	**Cultivated accessions**	**CWR accessions**
Abelmoschus	okra	81 (*A. esculentus*)	
Aegilops			875 (*A. comosa, A. triaristata, A. lorentii,* etc.)
Agropyron			21 (*A. elongatum, A. repens,* etc.)
Allium	onions and other allies	230 (*A. cepa, A. porrum, A. sativum*)	82 (*A. ampeloprasum, A. gutatum*, etc.)
Anethum	anise	50 (*A. graveolens*)	
Apium	celery	63 (*A. graveolens*)	
Arachis	groundnut	7 (*A. hypogaea*)	
Aristella			2 (*A. bromoides*)
Astragalus			79 (*A. hamosus*)
Avena	oat	59 (*A. sativa*)	3 (*A. sterilis*)
Beta	beet	481 (*B. vulgaris*)	314 (*B. nana, B. maritima*)
Biserrula			12 (*B. pelecinus*)
Brachypodium			8
Brassica	cabbages and kales	220 (*B. oleraceae*)	76 (*B. cretica*)
Briza			1 (*B. media*)
Calendula			2 (*C. officinalis*)
Capsicum	pepper	220 (*C. annuum*)	
Cicer	chikpea	222 (*C. arietinum*)	
Cichorium			6 (*C. endivia*)
Cistus			1 (*C. cretica*)
Citrulus	watermelon	124 (*C. lanatus*)	
Cucumis	melon and cucumber	383 (*C. melo, C. sativus*)	
Cucurbita	squash and pumpkin	304 (*C. maxima, C. moschata, C.pepo*)	
Cynara	artichoke	8 (*C. scholymus*)	
Dactylis			173 (*D. glomerata*)
Daucus	carrot	40 (*D. carota*)	22 (*D. muricatus*)
Dolichus	hyacinth bean	10 (*D. lablab*)	
Elletaria	cardamon		5 (*E. cardamomum*)
Festuca			41 (*F. arundinacea*)
Gossypium	cotton	306 (*G. hirsutum*)	
Haynaldia			86 (*H. villosa*)
Helianthus	sunflower	26 (*H. annuus*)	
Hipocrepis			23 (*H. unisiliquosa*)
Hordeum	barley	125 (*H.vulgare*)	75 (*H. bulbosum*, etc.)
Hymenocarpus			48 (*H. circinnatus*)
Lactuca	lettuce	138 (*L. sativa*)	
Lagenaria	Bottle gourd	43 (*L. siceraria*)	
Lolium			74 (*L. perenne*)
Lotus			110 (*L. corniculatus*, etc.)
Luffa	loofah	4 (*L. acutangula*)	
Lathyrus	grass pea	107 (*L. sativus*, *L. clymenum, L. ochrus*)	
Lens	lentil	119 (*L. culinaris*)	
Lupinus	lupin		86 (*L. pilosus, L. albus,* etc.)

Medicago			575 (*M. orbicularis, M. truncatula, M. arborea,* etc.)
Melilotus			8 (*M. albus, M. elegans*)
Mentha	peppermint, mint		4 (*M. viridis, M. pulegium*)
Nicotiana	tabacco	502 (*N. tabacum*)	
Onobrychis			1
Origanum	oregano, marjoram		23 (O. vulgaris, O. majorana, *O. dictamnus*, etc.)
Ornithopus			26 (*O. compressus, O.pinnatus*)
Oryzopsis			15 (*O. miliaceum*)
Panicum	millet	2 (*P. miliaceum*)	
Petroselinum	parsley	73 (*P. crispum*)	
Phalaris			8 (*P. tuberosa*)
Phaseolus	bean	919 (*P. coccineus, P. vulgaris*)	
Phleum			12 (*P. pratense*)
Pisum	pea	56 (*P. sativum*)	
Poterium			15 (*P. sanguisorba*)
Raphanus	radish	32 (*R. sativus*)	
Salvia	sage		23 (*S. officinalis, S. triloba*)
Scorpiurus			38 (*S. muricatus*)
Secale	rye	49 (*S. cereale*)	2 (*S. montanum*)
Sesamum	sesame	22 (*S. indicum*)	
Securigera			22 (*S. securidaca*)
Sideritis	mountain tea		6 (*S. syriaca*, etc.)
Solanum	tomato, eggplant, potato	580	
Sorghum	sorghum	5 (*S. bicolor*)	
Spinacea	spinach	42 (*S. oleraceae*)	
Thymus	thyme		15 (*T. capitatus, T. vulgaris*)
Trifolium			947 (*T. spumosum, T. arvense, T. stellatum*, etc.)
Trigonella			63 (*T. foenum-graecum, T. balansae, etc.*)
Triticum	wheat	261 (*T. aestivum, T. durum*)	44 (*T. boeoticum*)
Vicia	broad bean, vetch	321 *(V. faba, V. sativa*)	97 (*V. cracca, V. hyrbida, V. narbonensis,* etc.)
Vigna	cowpea	136 (*V. unguiculata*)	
Vitis	grapevine	270 (*V. vinifera*)	
Zea	corn	580 (*Z. mays*)	