# An empirical assessment of the effects of the 1994 In Trust Agreements on IRRI germplasm acquisition and distribution

Elisabetta Gotor
Associate Scientist Impact Assessment Spec., Bioversity International, Italy,
e.gotor@cgiar.org


Francesco Caracciolo
Department of Agricultural Economics and Policy, University of Naples 'Federico II', Italy,
Fra.caracciolo@gmail.com

**Abstract:** The objective of this paper is to assess the possible influence of the 1994 In Trust Agreements (ITAs) on acquisition and distribution of germplasm held by the International Research Rice Institute (IRRI) genebank. The agreements, legally affirmed the 'public good' status of the collections that were placed 'In Trust' for the benefit of the world community under agreements with FAO. They initiated a formal system of multilateral access to CGIAR-held *ex situ* genetic resources. The hypothesis that the consequences of the ITAs lead to an enhancement of CGIAR germplasm utilization is tested here using a basic conceptual framework to infer on factors determining the distribution of germplasm. Subsequently, a Bayesian empirical model is applied to IRRI accessions distribution's time-series to provide formal evidence to the hypothesis. Results show that there is a discernible 'change' point that would support a significant drop in germplasm distribution followed by a new growing trend around the establishment of the ITAs. This had followed a period beginning around 1989 and leading up to the establishment of the ITAs of a large number of requests for restoration of germplasm back to countries of origin and a reduction in acquisitions. As a result the number of accessions held by IRRI reached a low point around 1994. The number of accessions might not have been built back up without the establishment of a stable policy environment that was provided by the ITAs.

**Keywords:** Change-points, count data, crop genetic resources, germplasm collection, search theoretic framework

## 1. Introduction

The objective of this paper is to test the hypothesis that the consequences of the 1994 In-Trust Agreements lead to an enhancement of CGIAR germplasm utilization. In doing so formal investigations on factors affecting germplasm acquisition and distribution are conducted and a theoretical framework is developed through which it is possible to derive the demand of genetic resources (i.e. germplasm distribution) and explain how it is affected by its factors.

CGIAR germplasm collections were established with the intention of compiling genetic material of major staple crops in order to make it freely available for breeding. Subsequently germplasm availability for research and plant improvement to address problems of food security and productivity were also ensured. In this context the significance of the CGIAR collections is potentially enormous. The centres hold ~ 600,000 accessions, out of the 6 million accessions stored in over 1300 genebanks around the world (FAO's 1996 State of the World Report on PGRFA).

With the entry into force of the Convention on Biological Diversity (CBD) (Nairobi final Act) countries could begin to exercise their national sovereignty by increasing restrictions on access to Plant Genetic Resources (PGR). Therefore, CGIAR centres would have been compelled to comply with international law, if an ad hoc legal framework for the CGIAR material would not have been established. This means that without the ITAs countries that had contributed germplasm to CGIAR collections could demand its return or stipulate that CGIAR Centres holding the plant genetic resource material must limit its further distribution and use. Also countries hosting CGIAR Centre genebanks could consider germplasm held in those genebanks to fall under their sovereign rights because the material was technically located within the borders of that country (Gotor et al. 2008). It should be noted however that if on the one hand the real risk was that after the CBD some countries may have started questioning the distribution of germplasm samples by the CGIAR on the other hand, it is not certain that countries would have had the capacity to handle the material. Some of the donating countries in fact lacked key resources, including trained personnel, adequate facilities and appropriate legal frameworks to manage or distribute the germplasm themselves.

Overall it was generally perceived that policy uncertainty with respect to CGIAR genetic resources would impede the free distribution and acquisition of germplasm, including the flows occurring between CGIAR Centres, arming thus research on agriculture (Gotor et al. 2008). Even if exchanges did not completely decline, confidence in and thus funding for CGIAR germplasm collections could have collapsed. Such an outcome would have had a distinctly negative impact on research and development.

The 'public good' status of the collections was legally affirmed in 1994, when the germplasm collections were placed 'In Trust' for the benefit of the world community under agreements with FAO. These agreements initiated a formal system of multilateral access to CGIAR-held *ex situ* genetic resources. The expected impact of the agreements was to maintain flows of germplasm both to and from the CGIAR centres. The foundation of the Agreements is that CGIAR Centres do not regard themselves as owners, but rather trustees for these collections. They managed them on behalf of the beneficiaries, in particular developing countries, and they had the obligation to conserve the material to the highest technical standards, to duplicate it for safety reasons, to make it available without restrictions, and to seek no intellectual property right over it. This last obligation would include a transfer mechanism to avoid another party subsequently making the collections unavailable for research and breeding. The guarantee provided by CGIAR Centres was to ensure that the recipients of transferred germplasm and its related information were bound by the same conditions as the Centres themselves – neither to claim ownership over the designated germplasm nor to seek any intellectual property rights over that germplasm or related information.

In this study, an empirical application will be provided, in order to give statistical evidence of the *In-Trust* influence on the genetic stocks' distribution. As described above, the main hypothesis to prove statistically is the favourable impact of the agreements on the availability and utilization of CGIAR material, that given the uncertainty brought by the CBD, would have been lost.

The Chib's changepoints framework (1998) with latent state variable is selected to investigate the hypothesis because it is explicitly formulated to assess count data changepoints, and so particularly qualified in estimation process without the inclusion of other covariates. The estimations are conducted including data on genebanks utilizations and acquisitions provided by IRRI genebank. This study attempts to add some further empirical evidence to the studies conducted by Evenson and Gollin (1977) that using production function analysis have evaluated the economic role of IRRI in improving rice cultivars in respect to the average value of modern rice varieties and by Fowler et al. (2001) that examine CGIAR germplasm demand and subsequent use both in developing and developed countries.

## 2. The theoretican model: search-theoretic framework

The *search* methodology is introduced here as a viable tool to identify factors determining the distribution of germplasm. It assigns also a present value to

the expected future benefits of the research activity. In the *search-theoretic frameworks* benefits are compared to costs in order to optimize the search activity. In the PGRs case, the value of a single germplasm accession is shown by the product of the probability of discovering a valuable trait during the search process and its expected yield enhancement effects (Gollin et al. 2000). The search process however may be time-consuming and costly because of the activities required for the trait evaluation such as molecular screening or agronomic tests, in addition to germplasm acquisition and transaction costs (set by Zohrabian et al. 2003, at about 7$ per accession, per a single trait). This is an important aspect because often germplasm stored in public genebanks lack detailed information concerning genetic characterization and the likelihood that a single accession will be useful. Moreover breeding outcomes can be quite unpredictable because of the unpredictable nature of genotype environment interactions.

Search-theoretic frameworks* attempt to simulate the stochastic nature of breeding research and the successes and failures that they experience. When the probability of failure is non-zero, *search* can then be conducted in order to determine whether particular genetic traits may be useful. Evenson and Kislev (1976) gave impetus to several studies in valuing genetic stocks through this approach. That methodology, which is the first apply search theory to genetic resource evaluation, has roots grounded in a classic paper by Stigler (1961) who models consumer demand when a consumer, facing a price proposition, has uncertainty as to whether it is a minimum among possible alternatives. It is worth mentioning that this basic idea of Stigler (1961) spawned a vast growing literature related to job search, unemployment and related macroeconomic phenomena. An introduction to *search* formal analysis is contained in Sargent (1987), meanwhile Rogerson et al. (2005), present a recent literature survey on the subject.

The model we propose describes the salient features of the *search* process for the action '*choose the best of a set of possible outcomes from a set of random trials*.' In this context, we conceptualize the search process as one in which the investigator seeks to locate the genetic material that offers the maximum likelihood of return of the desired trait, for example resistance to a particular disease or elevation of a particular productivity measure. Each trial is an agronomic test; it involves genetic screening of a single accession that the investigator requests from a genebank.

Let $\mathbf{x} \equiv (x_1, x_2, \ldots x_N)'$ denote the vector of quantities (i.e. resistance score) obtained from N successive accessions or searches for a trait. We assume that these quantities are random variables emanating from a given probability distribution, that the trials are independent of one another, and that the draws can therefore, be modelled as *iid* draws from the given density or probability mass measure *f(x)*. If N denotes the number of such accessions we can focus our attention on $N^*$, which is the optimal number of accessions that the investigator should select. The optimum number is, of course determined by the relevant objective function

faced by the investigator. If we let $y_N \equiv \max\{x_1, x_2, \ldots, x_N\}$, we can consider the selection of the optimal level, $N^*$, as the solution to the problem

(1) $$\underset{N}{max} \ \Phi(N;) \equiv E\{U[\ Benefit(y_N) - Cost\ (y_N)]\},$$

where $U[\cdot]$ denotes utility derived from the search process. We assume that benefits obtained from locating the maximum value among the N accessions is completely described by the benefit function $Benefit(y_N)$ and also that the costs incurred in locating $y_N$ are completely described by the cost function $Cost(y_N)$. Let us suppose that for each successful realization of the N trials – each $y_N$ – the investigator receives a benefit of the amount $\alpha > 0$, so that the benefit function assumes the form $Benefit(y_N) \equiv \alpha\ y_N$. How the quantity $\alpha$ is calculated, revealed or determined we are unable to answer at this point. In addition, if we assume that each search-and-screening exercise incurs a constant per unit cost $\kappa > 0$, then the cost of N such trials – the cost of realizing $y_N$ – is $Cost(y_N) \equiv \kappa N$. It follows that the utility derived from transacting N accessions is $U[\cdot] \equiv \alpha\ y_N - \kappa N$. In order to make further progress we note that if we also knew the form of the distribution $f(x)$ from which the realizations $x_1, x_2, \ldots x_N$ are drawn, we could assess the actual form of the objective function in equation (1). Consequently, we could proceed to model the demand for accessions, namely the optimal value $N^*$ that is chosen by the investigator. Indeed such an assumption should be supported by an appropriate empirical exploration, and the empirics to follow provide some indications. In this context, and the desire at this point purely to simplify we adopt Stigler's (1961) assumption that the distribution $f(x)$ is uniform, on the standardized interval $[0,1]$[1].

Using this assumption the first-order required condition, which is also sufficient for a maximum, is

(2) $$\Phi(N;\alpha,\kappa) \equiv \frac{\alpha(N+1) - \alpha N}{(N+1)^2} - \kappa = 0.$$

It is trivial to establish that the solution to this equation, $N^*$, increases with increasing $\alpha$ and declines when increasing $\kappa$, as one would expect in a realistic search situation with increasing value of the benefits derived and costs incurred. Using this simple idea we can motivate changes in the demand for accessions – that is, changes in the value $N^*$ – as a result of changes arising in the perceived costs and benefits of sourcing accessions. In this way, we are able to motivate changes in the counts data associated with the trend of accessions.

## 3. Data used

Prior to considering the results we present a broad overview of some of the data made available to us by the IRRI genebank. The International Rice GeneBank

---

[1] For full details of our assumptions and calculations see Appendix A.

Collection (IRGC) at IRRI comprises the largest collection of rice germplasm held In-Trust for the world community (McNally et al. 2006). In fact, out of 109,055 accessions collected worldwide from 1961 to 2006, 102,899 (94.4%) are In-Trust whereas 6156 (5.6%) are non In-Trust. 102,901 accessions belong to Asian cultivated rice (*Oryza sativa*), of which 96,995 (94.2%) are In-Trust and 1656 accessions are African cultivated rice (*Oryza glaberrima*), all of which are kept In-Trust. IRRI maintains records of breeding pedigrees of all modern rice varieties derived from mating traditional varieties (McNally et al. 2006). As shown in Figure 1 the acquisition trend changes significantly over time.

Overall, Figure 1 shows that accession contributions had a wave motion over the years due to different causes. Factors affecting germplasm flows in fact could be located in the CGIAR genebank, at the level of the country, researcher providing or requesting germplasm. For example research funding and collecting strategies within IRRI play an important role in germplasm acquisition. According to the Head of IRRI Genetic Resources Centre the peak of germplasm acquisition during the 1970s shown in Figure 1 was relating to the availability of high levels of core funding and the strategic goal to establish a large and diverse collection. The second peak during the late 1990s instead was relating to a specific project aimed at "completing" the collection by acquiring germplasm from 22 countries (*Head of IRRI Genetic Resources Centre personal comment*). The decrease of acquisitions in the 80s and 90s was relating to the adoption of more directed and efficient acquisition strategy rather than a lack of funds or political uncertainty (*Head of IRRI Genetic Resources Centre personal comment*). Adding a new accession to the collection in fact adds a fixed amount to operational costs of conserving regardless of the size of the collection, but gives diminishing returns as the size of the collection increases. That is, adding a new accession to a large
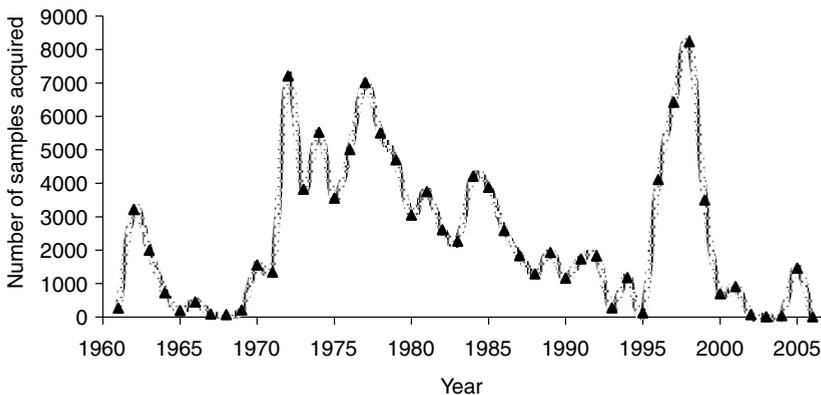


Source: IRRI genebank database

*Figure 1: IRRI Germplasm acquisitions 1961–2006.*

collection may add little or no value to the collection if it duplicates material already conserved. Therefore, as the collection grew IRRI had to be increasingly careful to ensure that new accessions added value.

Studies by Pardey et al. (1999, 2001) and Koo et al. (2003) evaluated costs of collecting and conserving accessions. The objective was to enact a conservative evaluation of marginal accession costs, in order to justify germplasm conservation if the costs result to be generally less than the potential benefits conferred. Pardey et al. (1999, 2001), exploit microeconomic concepts in order to extract marginal accession costs, and calculate the amount of the endowment necessary to ensure endurable future conservation for the genetic materials held by the CIMMYT genebank. The same methodology was applied later by Koo et al. (2003), to value the resources held by CGIAR genebanks. The investigations highlight the insignificance of the costs of holding resources compared to the present and future potential benefits that are available.

Table 1 shows the 10 countries that contributed the most accessions to IRRI, with India, Laos, Indonesia and China, accounting for 44% of the total IRRI accessions. It is however, interesting to note how the attitude toward donations changes pre and post 1994. In fact, India before the entry into force of the CBD was a major donor country, donating an annual average of 507 samples, this number dropped to 2 after 1994. Current Indian policy in fact does not allow the usage and conservation of the material conserved in genebanks outside India. The end result of this is that more of India's rice diversity is likely to be conserved in India than in the IRRI genebank. The M.S. Swaminathan Research Institute in fact estimates that 100,000 traditional varieties are still in use by farmers in India and another 300,000 have become extinct since agricultural intensification (*Head of IRRI Genetic Resources Centre personal comment.*). IRRI's collection of about 16,000 traditional and modern Indian varieties represents only a fraction of this diversity. In Indian trials of varieties suitable for soils damaged by the 2006 tsunami, the six most promising varieties were all traditional varieties not held within the IRRI

*Table 1: Germplasm acquired by IRRI from top 10 contributing countries (1961–2006).*

| Country | Total Acquired | Acquired pre 94* | Acquired post 94* |
|---|---|---|---|
| India | 16,770 | 507 | 2 |
| Laos | 15,362 | 61 | 1027 |
| Indonesia | 9099 | 507 | 2 |
| China | 8105 | 232 | 34 |
| Philippines | 6651 | 133 | 173 |
| Thailand | 6348 | 180 | 32 |
| Bangladesh | 6166 | 179 | 21 |
| Cambodia | 4875 | 56 | 233 |
| Malaysia | 4269 | 95 | 88 |

*Average per year.
Source: IRRI genebank database.

collection. Moreover, Indian scientists have been continuing to collect traditional Indian varieties of rice from all over India. They are conserved in the National Bureau of Plant Genetic Resources in New Delhi, which now has a much larger and more diverse collection of Indian rice than IRRI. On the other hand, countries such as Laos, increased distribution after 1994 (the IRRI increase of accessions in 1994 shown in Figure 1 is actually due mostly to Laos), accounting for an annual average of 1027 samples given to IRRI. IRRI's collection of accessions originating from Laos (of ~ 15,000 accessions) is considered to be very complete and is a large representative of Laos' diversity. For this reason, Laos may have been motivated to continue to be actively engaged with the IRRI collection and this engagement is reflected in the continued contributions of germplasm.

The case of India provides evidence on how countries that rejected the multilateral system of germplasm exchange, did not want to lose their sole proprietary rights to their indigenous germplasm resources, denying thus the free exchange of their material.

Figure 2 shows the trend of germplasm distributed by IRRI for different purposes; restoration of germplasm to host countries, use within the IRRI research programme and a broad category that includes all other purposes. Germplasm distributed within IRRI presumably would not be affected by any political uncertainty about the status of the collection since IRRI scientists can use the material freely. The germplasm distributed by the IRRI genebank to IRRI scientists showed two peaks in 1991 and 2002. These coincide with the arrival of new staff and management at the genebank who undertook a series of interviews and seminars that might have created knowledge and awareness among IRRI scientists about the germplasm, and thus led to an increase in demand of germplasm.
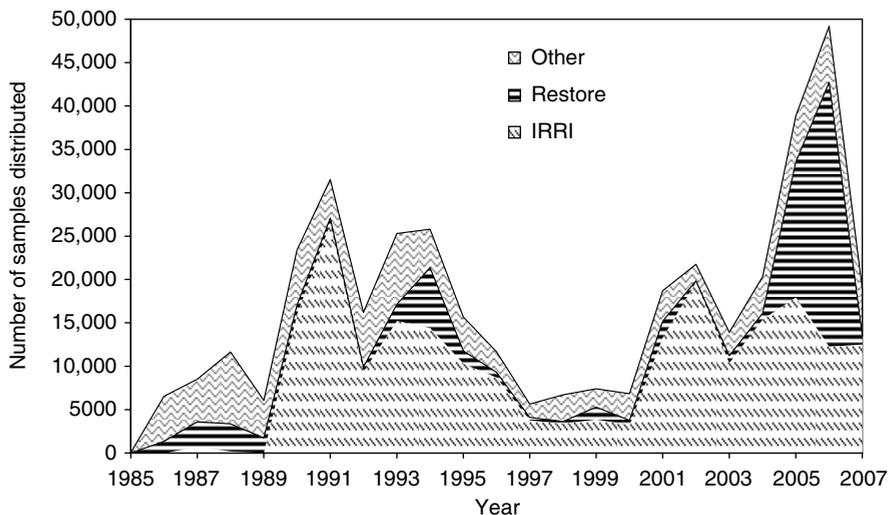


*Figure 2: IRRI Germplasm distribution 1983–2006.*

Germplasm distributed for restoration and for other purposes could well have been affected by, among other factors, political uncertainty since its free distribution is depending upon the legal status attached to the accessions. Special attention to the germplasm distributed for restoration, which is understood to be germplasm distributed to country of origin for restoration purposes is posed here. Figure 2 shows two peaks of germplasm distributed for restoration in the 90s and from 2004 to 2006. The peak years coincide with the period of uncertainty brought about by the CBD and in 2006 with the introduction of a new Standard Material Transfer Agreement (SMTA) that governed procedures for germplasm transfers associated with the International Treaty. The first peak in Figure 2 will be at the centre of our attention in order to empirically understand if an actual change point in germplasm distribution is coinciding with the entry in to force of the CBD has occurred or not and the likely implication of the ITAs for germplasm distribution. This choice is emphasized further by the results reported by Gotor et al. (2008) that pointed out that as a result of the CBD, "… *real possibility of acrimonious international demands of returns of some collections…*" would have happened, and "*germplasm exchange would have come to an end* [if an agreement would not have been reached] *because the International Agricultural Research Centres (IARCs) could hardly operate outside the international law.*

## 4. An empirical assessment of the effects of the In Trust agreements on IRRI germplasm acquisition and distribution

The purpose of this section is to develop more formally the notion that the 1994 In-Trust agreements had an impact on the flow of genetic resource materials, specifically the germplasm distributed for restoration. In this respect, an ideal 'laboratory' would enable us to determine formally, statistically, the complete trajectory and patterns of genetic material exchange had the agreements not materialized. Unfortunately, such an objective, despite its considerable merits, is simply not possible in the current state of science. What we do have available are the patterns of exchanges both prior to and immediately following the agreements. The question upon which we focus our attention is whether, given this pattern of stock exchange, the 1994 period brought any discernible change in its movement, either in the upwards or in the downwards directions.

This impact, we posit must have been a decidedly favourable one. For example, one crucial impact of the In-Trust Agreements is lowering transaction costs of germplasm's accessions exchange (Visser et al. 2000). Because the agreements assured a clear legal status to the genetic resources, making them 'freely' available it removed a degree of uncertainty regarding property rights to the resources that characterized the period immediately following the Convention of Biological Diversity's enactment (1993) lowering therefore the bargaining costs (i.e. negotiation of an agreement) which are dependent on the legal status. Again this trend is recorded in 2006 when a new Standard Material Transfer Agreement (SMTA) was introduced. In this scenario we assume that

thanks to the agreements, the demand for "*In Trust*" PGR should be relatively enhanced, increasing the genetic stocks direct-use value (*search value*), and consequently providing an economic improvement of the CGIAR collections' value.

In order to assess whether a structural change occurred in the demand of germplasm a wide range of models exists; change-point models in time series analysis to test for the presence of a structural break are widely used. A change-point framework due to Chib (1998) which is attractive because to assess count data change-points it is formulated explicitly and so particularly qualified in estimation process without the inclusion of other covarieties, other factors affecting the germplasm demand, is chosen as a tool of analysis. The Chib's change point formulation was applied to the data, as shown below (Chib 1998), on IRRI germplasm distributed for restoration.

The count in year t, $y_t$, is modelled via a Poisson relation:

(3)[2]                                              $$f^P(y_t|\xi_t) \equiv \xi_t^{yt} \exp\{-\xi_t\}/y_t!$$

The estimation is executed imposing only one change-point in the time-series for the distribution of samples for restoration. We focus on this sub-category because according to Figure 2, it seems to be the time series that is perhaps most affected by the ITAs.

The posterior means for $\lambda_1$ and $\lambda_2$ (the Poisson parameters of the two identified distributions), are respectively 3275 and 2828. The model performs efficiently, identifying as the change-point the period $t = 13$, occurring at the point of intersection of the two probabilities of $s_t$ corresponding to the year 1995 (Figure 4). The figure shows the probability that the process falls in each of the two states for all years. The change-point marks the beginning of a new rising trend of the distributed germplasm. Thus, casual empirical evidence, supported by formal analysis

*Table 2: Chib change-point results.*

| Parameters | Mean | Standard deviation | Quintiles for each variable | | | | |
|---|---|---|---|---|---|---|---|
| | | | 5% | 25% | 50% | 75% | 95% |
| $\lambda_1$ | 3275 | 49.1 | 3196 | 3247 | 3275 | 3314 | 3356 |
| $\lambda_2$ | 2828 | 44.3 | 2753 | 2797 | 2827 | 2857 | 2900 |

Source: Authors calculations.

---

[2] Where: $y_t$ denotes the count in the year t and the density of $y_t$ is function of the parameter $\xi_t$. The value of $\xi_t$ changes at unknown time points, $\Gamma_m = \{\tau_1, \ldots, \tau_m\}$. In a two- change-points model, for example, $\Gamma_m = \{\tau_1, \tau_2\}$, $\xi_t$ is subjected to two breaks, one at time $\tau_1$ and another at time $\tau_2$ such that $\xi_t = \lambda_1$ for $t \leq \tau_1$, $\xi_t = \lambda_2$ for $\tau_1 < t \leq \tau_2$ and $\xi_t = \lambda_3$ for $\tau_2 < t \leq n$, where $\tau_1 > 1$ and $\tau_2 < n$. The estimation effort is focused on the vector of the parameters $\lambda$, and on the unknown change points $\Gamma_m$ (see Appendix B for full details).
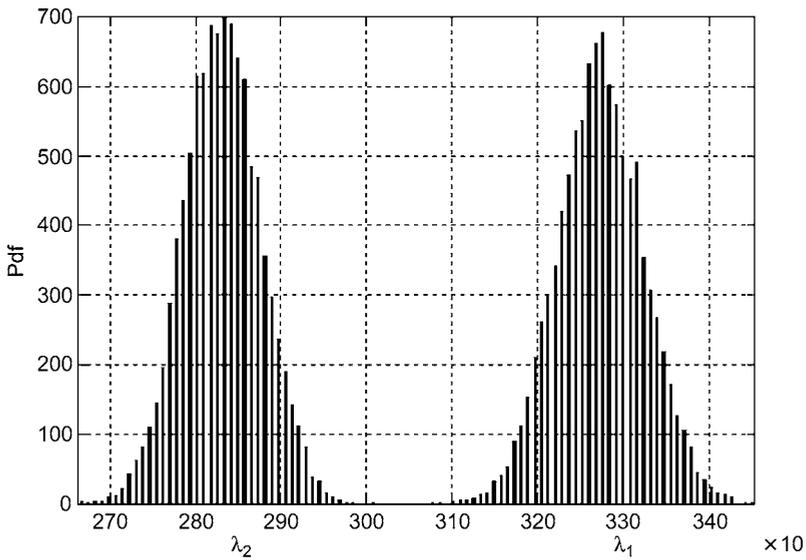
Source: Authors calculations

*Figure 3: Posterior marginal densities of $\lambda_1$ and $\lambda_2$.*
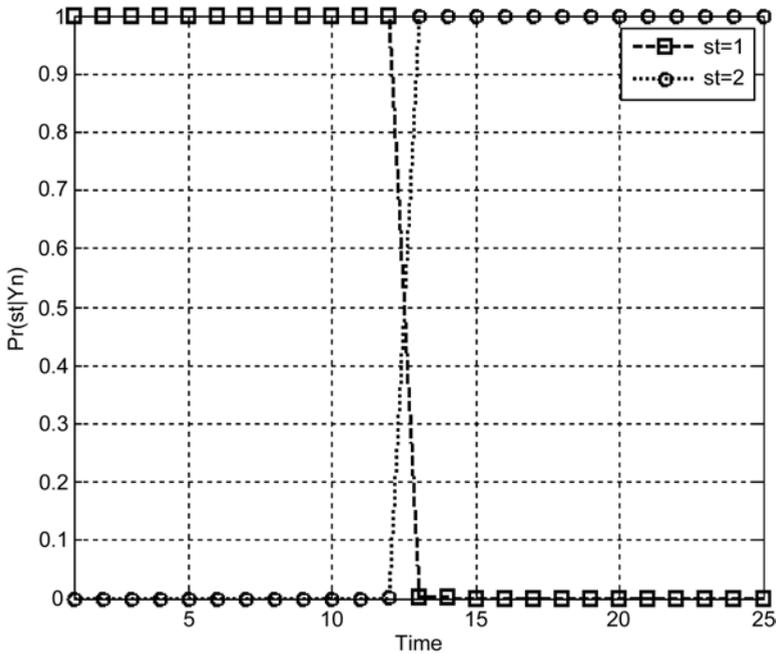


Source: Authors calculations

*Figure 4: Pr(st=k|Yn), Germplasm demand dataset.*

seems to suggest that a significant change emerged immediately following the establishment of the In-Trust agreements in the germplasm distributed for restoration to country of origin.

Of course, attributing such a switch to a single event would not reflect the reality of the situation, where many issues related to both policy and other factors would affect requests for and actual distribution of germplasm. However, as Gotor et al. (2008) demonstrated throughout a qualitative analysis based on semi-structured interviews to key informants, the analysis supports the possibility that the ITAs and the accompanying political environment would have had a significant positive affect on germplasm distribution.

As a result of the increased demand for germplasm material for restoration combined with the overall reduction in acquisitions, the actual size of IRRI genebank would have diminished considerably posing the likely scenario of not having germplasm exchange and even if germplasm collections would not have fully dismantled, surely would not have been found anymore (Gotor et al. 2008). Gradually as the policy environment became more stable, the genebank was able to build up its holdings to the pre-CBD level. However, if the policy environment had not stabilized it is possible that the number of accessions would not have been able to recover (Gotor et al. 2008).

## 5. Conclusions

The In-Trust Agreements, signed in 1994 between FAO and 12 CGIAR Centres, were the result of a lengthy process of protracted negotiations that had the single objective of regulating CGIAR germplasm, its acquisition and its distribution. A considerable challenge existed. This challenge was to find an agreement that could accommodate the needs of a heterogeneous set of key stakeholders. These stakeholders involved as many as twelve heterogeneous research centres, with distinct boards of trustees, distinct directorships and distinct internal infrastructures; and twelve distinct states, each with their own idiosyncratic regulations and legal infrastructures. The feasible solution that emerged was to apply to CGIAR collections the concept of 'trusteeship.' The key contribution of the In-Trust Agreements is that there was an internationally recognized accord for the multilateral exchange of PGR, which in turn has prepared the ground for further multilateral agreements on PGR.

The ITAs represent one stage of a continuing, dynamic process in implementing and adapting the CBD regime to the characteristics of the agricultural sector. The reduction of transaction costs should be analyzed further within its dimension of reducing bargaining costs associated with the monitoring and enforcement costs. In fact the adoption in 1998 of a Second Joint Statement of FAO and the CGIAR Centres on the "Agreement Placing CGIAR Germplasm Collections under the Auspices of FAO" includes some provisions regarding monitoring and enforcement of the terms of the Material Transfer Agreement (MTA). Under the Statement, CGIAR centres and FAO agree to share

responsibilities to monitor compliance with the provisions of MTA and to take legal action against possible infringers. Finally, the signature of the Agreement under article 15 of the International Treaty is of course the last stage reached toward this progress but it is still too early to draw any conclusion with existing data.

There is discernible 'change' evident in the statistical analysis of distribution data from the IRRI rice collection that would support a significant drop in germplasm distribution followed by a new rising trend around the establishment of the ITAs. This had followed a period beginning around 1989 and leading up to the establishment of the ITAs of a large number of requests for restoration of germplasm back to countries of origin and a reduction in acquisitions. As a result, the number of accessions held by IRRI reached a low point around 1994. Without the establishment of the stable policy environment that was provided by the In Trust Agreement the number of accessions might not have been built up again.

## Literature cited

Chib, S. 1998. Estimation and comparison of multiple change-point models. *Journal of Econometrics* 86(2):221–241.

Evenson, R., and Y. Kislev. 1976. A stochastic model of applied research. *Journal of Political Economy* 84(2):265–282.

Evenson, R. E., and D. Gollin. 1977. Genetic resources, international organizations, and improvement in rice varieties. *Economic Development and Cultural Change* 45(3):471–500.

FAO. 1996. *The State of the World's Plant Genetic Resources for Food and Agriculture*. Rome: FAO.

Fowler, C., M. Smale, and S. Gaiji. 2001. Unequal exchange? Recent transfers of agricultural resources and their implications for developing countries. *Development Policy Review* 19(2):181–204.

Gollin, D., M. Smale, and B. Skovmand. 2000. Searching an ex situ collection of wheat genetic resources. *American Journal of Agricultural Economics* 82(4):812–827.

Gotor, E., F. Caracciolo, and J. Watts. 2008. The impact of the in-trust agreements on CGIAR germplasm exchange and the role of bioversity international in establishing the agreements. In *Impact of policy-oriented research in the CGIAR – case study results*. Rome, Italy: Science Council Secretariat, 15–24.

Koo, B., P. G. Pardey, and B. D. Wright. 2003. The economic costs of conserving genetic resources at the CGIAR centres. *Agricultural Economics* 29(3):287–297.

McNally, K., R. Bruskiewich, D. Mackill, C. R. Buell, J. E. Leach, and H. Leung. 2006. Sequencing multiple and diverse rice varieties. Connecting whole-genome variation with phenotypes, *Plant Physiology* 141(1):26–31.

Pardey, P. G., and International Food Policy Research. 1999. *Costing the ex situ conservation of genetic resources: maize and wheat at CIMMYT*. International Food Policy Research Institute; Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT).

Pardey, P. G., B. Koo, B. D. Wright, M. E. Van Dusen, B. Skovmand, and S. Taba. 2001. Costing the conservation of genetic resources CIMMYT's Ex Situ Maize and Wheat Collection. *Crop Science* 41(4):1286–1299.

Rogerson, R., R. Shimer, and R. Wright. 2005. Search-theoretic models of the labor market: a survey. *Journal of Economic Literature* 43(4):959–988.

Sargent, T. 1987. *Dynamic Macroeconomic Theory*. Cambridge, MA: Harvard University Press.

Stigler, G. J. 1961. The economics of information. *Journal of Political Economy* 69(3):213–225.

Visser, B., D. Eaton, N. Louwaars, and J. Engles. 2000. Transaction costs of germplasm exchange under bilateral agreements. Document No. GFAR/00/17-04-04. Global Forum on Agricultural Research. FAO, Rome.

Zohrabian, A., G. Traxler, S. Caudill, and M. Smale. 2003. Valuing pre-commercial genetic resources: a maximum entropy approach. *American Journal of Agricultural Economics* 85(2):429–436.

## Appendix A

Associated with the probability distribution function $f(x)$ is a cumulative distribution function, $F(h) = \int_{-\infty}^{h} f(x) \, dx \equiv \wp(x \leq h)$. In the case of the unit uniform distribution we have $F(h) = \int_{0}^{h} 1 \, dx = h$. Using standard derivations the task of locating the maximum can be formalized in probabilistic terms in a step-wise fashion. The first step is to derive the cdf corresponding to the maximum within the sample, which we denote $F_{yN}(y) = \wp[y_N \leq y] = \wp[x_1 \leq y; \, x_2 \leq y; \, \ldots ; \, x_N \leq y]$. Now, if the screenings are, in fact, independent draws we have $F_{yN}(y) = \prod_i \wp[x_i \leq y] = \prod_i F_{xi}(y)$. If the draws are made from the same distribution – a reasonable assumption – we then have $F_{yN}(y) = F_x(y)^N$. Consequently, the pdf associated with $y_N$, which is obtained by differentiating, is $f_{yN}(y) = N[F_x(y)]^{N-1} f_x(y)$. Finally, using the fact that the originating distribution $f_x(\cdot)$ is standard uniform, we obtain $f_{yN}(y) = N \, y^{N-1}$, which is clearly a function of $N$, as well as $y$. An explicit solution to the optimization problem in equation (1), which now reduces to

$$(1b) \qquad \max_N \Phi(N;\alpha,\kappa) \equiv \int_{y_{max}}^{y_{min}} \alpha \, N \, y^N \, dy - \kappa \, N,$$

where, we note, $y_{min}$ and $y_{max}$ are, respectively, the minima and maxima available across the support of the standard uniform distribution, that is, $y_{min} = 0$ and $y_{max} = 1$, respectively. Using this fact, the first-order necessary condition, which is also sufficient for a maximum, is equation (2).

## Appendix B

Within each period Chib introduces a latent class predictor, '$s_t$,' referred to as the 'state' of system at time t, corresponding to the m+1 phases in which the samples can be split. This latent state variable is formulated in a way to evolve according to a discrete-time, discrete-state Markov process with the transition probability matrix, $\wp$, forced so that $s_t$ either remains at the current value or jumps to the next highest value. The count in year t, $y_t$, is modelled via a hierarchical Poisson relation (3). Specifically, his variable '$s_t$' is an integer defined on the set of integers $\{1, 2, \ldots, m+1\}$ corresponding to the m+1 possible phases into which the time series can be subdivided. Thus, a realization $s_t = k$ signifies that observation 't' emanates from state 'k' of the system. In other words, that observation $y_t$ evolves from the distribution $f(y_t|\mathbf{y}_{t-1}, \theta_k)$, where $\mathbf{y}_{t-1} \equiv (y_1, y_2, \ldots, y_{t-1})'$ denotes observations up to time t–1 and $\theta_k$ denotes the parameters determining state $k$ of the system. The variable is modelled as a discrete-time, discrete-state Markov process with the transition probability matrix constrained so that the model is equivalent to the change-point model. In this context, the transition probability matrix formalizes the notion that $s_t$ can either remain at the current value or jump to the next highest value. Thus, the one-step-ahead transition probability matrix is represented as

$$
(4) \qquad \wp = \begin{bmatrix} p_{11} & p_{12} & & & \\ & p_{22} & p_{23} & & \\ & & & & \\ & & & p_{mm} & p_{m,m+1} \\ & & & & 1 \end{bmatrix},
$$

where $p_{ij} = \text{Prob}(s_t = j|s_{t-1} = i)$ denotes the probability of moving to regime j at time t given that the regime at time t–1 resides in regime i. Now, defining $\mathbf{S} \equiv (s_1, s_2, \ldots, s_N)'$ as the unknown or latent class of states; and defining $\theta \equiv \{\theta_1, \theta_2, \ldots, \theta_{m+1}\}$, attentions focus on the posterior defined over the quantities $\theta$, $\wp$ and $\mathbf{S}$. Chib (1998) then derives the general forms of the conditional distributions for $\wp$ and $\mathbf{S}$ and notes that the distributions corresponding to $\theta$ are model-specific. The state probabilities have a Bernoulli distribution with mass-points derived form the complete-data likelihood; and the non-zero components of $\wp$, above, have a Beta distribution.