EVALUATING THE RISKS AND BENEFITS OF GENETICALLY MODIFIED AGRICULTURAL PRODUCTS IN THE GLOBAL MARKETPLACE

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1 INTRODUCTION

Humans have manipulated the genetic composition of crop plants for thousands of years, and biotechnology has played a critical role in global agriculture since the start of the green revolution in the mid 1900s[1]. The very recent advent of transgenic crop enhancement, resulting in the crop plants commonly referred to as genetically modified organisms (GMO)[2], has stirred significant debate between those who see GMOs as key to a host of remarkable new possibilities, and those who see them as a Pandora's Box.

But at the heart of the controversy lies a blurred distinction between the scientifically assessed riskiness of GMO use and the perceived riskiness as it emerges within public opinion and public policy. To the extent that perceived GMO risk varies throughout different parts of the world, and to the extent that agricultural markets connect these very same parts of the world, divergent perceptions of the risk can have considerable impacts on the use or disuse of GMOs in particular countries.

The controversy comes to a head when two or more countries assess the balance of potential risks and benefits of GMO use differently and, whether intentionally or inadvertently, impose their own assessments of the balance on one another. Indeed, international market forces appear to have just this type of effect on GMO development and use. Negativity towards GMO use, particularly in European, Japanese and Korean markets[3], has effectively suppressed the development and use of GMOs in a number of other countries and appears to have curtailed (at least partially) the spread of GMO use throughout many parts of the world.[4] This has led many developing countries that were

[1] van den Bergh and Holley
[2] Biotechnology is distinct from transgenic technologies in that the latter is a subset of the former. Many of the crop enhancement methodologies developed and extensively used throughout the green revolution are biotechnologies, while only a subset of recently developed transgenic crop enhancement methodologies result in what are commonly known as genetically modified organisms.
[3] Paarlberg, Robert L. (a)
[4] See Juma, Calestous or Paarlberg, Robert L. (a)

exploring GMO use to suppress those efforts for fear of losing access to key import markets.[5]

Yet there is reason to be optimistic that development of GMOs over the long term has the potential to provide much benefit to both developed and developing countries, such as net environmental improvements due to reductions in the use of pesticides and fertilizers; reduced water requirements; enhanced crop capacities to grow in high salinity, arid, or acidic soils; and nutritional enhancement of staple crops.[6] Thus, a concern is that extreme negativity toward GMOs now could prevent the development of largely beneficial GMOs in the future.

Given the present level of understanding, precisely how the potential risks and benefits of GMO use in general balance out remains an open question. Very real and significant risks have been identified, and further potential risks have been realistically hypothesized. But the opinion amongst many scientific authorities is that while GMOs pose uncertain and potentially damaging risks, such risks are not significantly different than those associated with other means of genetic manipulation that humans have used to breed crop plants since the green revolution and, to a lesser extent, for many years prior[7]. Furthermore, because the risks vary considerably between different GMO products, it makes very little sense to speak about the risks of GMOs en masse; rather, it becomes necessary to explicitly investigate the potential risks of each individual GMO product being considered for use.[8]

Such opinions, of course, are at loggerheads with those who believe that the development and use of GMOs is progressing far too rapidly, and that the discipline is subjecting people and the environment to undue risk. At the extreme, agents of this

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[5] Ibid.
[6] See, among others, Nuffield Council on Bioethics
[7] See, for example, National Research Council
[8] Jank and Gaugitsch

opinion argue for a full moratorium on GMO use until it can be proven that there is zero risk incurred from their use. Such extremes, however, do little to inform a rational decision making process, as technological developments of this nature can never reasonably be expected to present zero risk. Furthermore, in pursuing such discussion, one must necessarily recognize that even conventional agricultural production processes, with their tendency to simplify and destabilize natural environments, are not free of many of the types of risk that are commonly attributed to GMOs.[9] In sum, to require zero risk as a prerequisite for GMO use is to forego its development and all its potential benefits entirely.

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The intention of this paper is to investigate the territory between the polarized extremes of the GMO debate. It proceeds under a maintained assumption that any market suppression of GMOs which prevents the further development and adoption of these crop products imposes opportunity costs on any potential GMO user who may have garnered benefits from their use. But it recognizes a need to analyze this in comparison with the potential risks so as to assess the balance and begin thinking critically about what defines the optimal level of GMO development and adoption. Indeed, a fundamental purpose here is to establish a balancing test under which we can assess the potential risks versus potential benefits of GMO use.

Adding complication to this analysis is the varied preferences towards GMO risk among different users in different regions of the world. The investigation extends between and across the dichotomous categorization of developed versus developing countries, and in fact presents some very interesting and important implications. Further adding to the calculus is the capacities of developing countries to safely and effectively

[9] National Research Council

manage this new and as of yet still uncertain technology. While GMOs may present unique opportunities for poor people in developing countries, one must also recognize that certain fundamental deficiencies in such countries may in fact enhance the risks associated with GMO use.

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The remainder of this introductory section provides some background on the GMO market and some of the substantive issues surrounding the risks and benefit of their use. Section 2 discusses national policies on GMO and the interplay of these with international markets. Section 3 explores the question of preferences toward risk from within the parameters of a microeconomic treatment of risk. Section 4 provides a review of some empirical analyses that have been carried out with regard to the question at hand, and provides discussion on the implications of these findings vis-à-vis the issues presented throughout the paper. Section 5 sets the tenets of section 3 opposite to those of section 4, presenting a balance or scale by which to consider the risks and benefits of GMO use, and draws conclusions about the role of GMOs in a world of risk aversion.

1.1 Global GMO Production in 2003

In 2003, eighteen countries grew approximately 50,000 hectares of GMO crops. [10] By means of comparison, 1357.8 million hectares of land was used for agricultural production worldwide in 1995.[11] Of the 50,000 hectares of GMO growth in 2003, 99% of was concentrated in six countries. The United States ranked first among these, with 63% of the world total, followed by Argentina with 21%, Canada with 6%, Brazil with 4%, China with 4%, and South Africa with 1%.[12] The remaining one percent was divided between Mexico, Honduras, Colombia, Uruguay, India, Indonesia, Australia, Romania,

[10] James, Clive. Pg 4
[11] UN Food and Agricultural Organization Statistics; available from http://www.fao.org/WAICENT/FAOINFO/ECONOMIC/ESS/chartroom/default.asp
[12] James, Clive. Pg 4

the Philippines, Bulgaria, Germany and Spain. Brazil and the Philippines approved the use of GM crops for the first time in 2003.[13] In dollar terms, the 2003 market value of GM seed plus any applied technology fees was estimated at $4.5 to $4.75 billion. This value is projected to hit $5 billion in 2005.[14]

Four crop types, soybean, corn, cotton and canola, currently account for all commercialized GMO agriculture worldwide. While they do account for a very small percentage of total worldwide agriculture, it is interesting to note their usage in comparison to their conventional counterparts. In 2003, GM soybeans accounted for 55% of worldwide soybean production, GM cotton for 21% of worldwide cotton production, GM canola for 16% of worldwide canola production, and GM maize for 11% of worldwide maize production.[15]

1.2 The State of the GMO Art

Currently, all commercially available GMO products are engineered with producer interests in mind. Essentially, the benefits can be broken down between two categories: pest resistance and herbicide resistance. *Bacillus thuringiensis,* commonly referred to as *Bt*, is the most widely discussed genetic modification for pest resistance. *Bt* is a naturally occurring insecticide that has been used for decades as a repellent and, interestingly enough, by organic farmers as a certifiably organic method of pest control. The toxin can be genetically isolated and inserted into crop genes, and is now commonly seen in corn. Concern over *Bt* use focuses predominantly on the possibility of enhancing pest resistance to the *Bt* toxin, and is particularly contentious among organic farmers who would lose this means of non-chemical pest control if pest resistance increased markedly. It has also been criticized for having caused high death rates in monarch butterfly larvae during laboratory

[13] James, Clive. Pg 5
[14] James, Clive. Pg 6
[15] James, Clive. Pg 5

tests, a result that fuels further debate on the effects that GMOs may have on "unintended targets." These clinical tests have, however, been highly criticized on grounds of methodology.[16]

Herbicide resistant GMOs are engineered so that farmers can spray a field with herbicides to kill weeds after the crops have sprouted. Alternatively, farmers generally spray their fields preemptively, requiring some degree of guesswork as to what type and how much herbicide to apply. Studies of herbicide resistant cotton have shown increased yields and net returns while using equivalent quantities of herbicide. Herbicide resistant soybeans have generated small increases in yield but with significantly reduced quantities of herbicide use.[17] Among the concerns associated with herbicide resistant crops is the possibility of breeding "superweeds" that become very difficult to control.

While the benefits of this first generation of GM crops are producer oriented, there are residual benefits that accrue to consumers. Certainly, increases in output or decreases in production cost will result in lower consumer prices. But beyond this is the expectation that future GMOs may one day provide benefits explicitly directed at consumers' interests. Perhaps the most widely discussed of these probable, but still largely hypothetical, GMOs are nutrient enhanced food staples such as rice. The oft sited *Golden Rice*, with its enhanced *vitamin A* content, may one day be effective at reducing blindness in poorly nourished children in developing countries.[18] Other proposed possibilities include the capacities to derive and administer vaccinations, enhance other nutritional contents, and provide necessary supplements via an essentially automatic mechanism.[19]

To the extent that reductions in the use of pesticides and herbicides might favorably affect surrounding water quality, soil quality, and general environmental

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[16] van den Bergh and Holley Pg 5
[17] Ibid.
[18] See Nielsen and Anderson (July 2003)
[19] See National Research Council pg 226, as well as Timmer

welfare, GMOs can offer further benefits to non-producers. Environmental benefits of GMO use are only beginning to be understood, but among the potentialities are reduced use of synthetic insecticides and herbicides (which in turn yields human health and water quality benefits), increased output per acreage and the resulting reduction in synthetic fertilizer requirements, elimination or vast reduction of tillage requirements (benefiting soil erosion and aeration), and a number of other possibilities.[20] Of course, many of these benefits are contingent upon proper use and application by the farmer, and therefore the capacities of farmers to manage GMOs accordingly must be taken into account when estimating net benefits.

Some of the strongest environmental arguments against GMO use include the potential for unanticipated gene mixing, contamination of soils, damage to non-target species, enhanced pest resistance, and the evolution of 'superweeds'.[21] Yet, most scientists believe that these risks are not unique to GMOs. A common strain throughout much of the scientific literature is that environmental risk (and for that matter human health risks) associated with GMO use are a function of trait novelty in general. That is to say, all agricultural crops that have been altered by humans, whether via transgenic methods, mutagenesis, hybridization, or otherwise, carry novel genetic properties. Novel genetic properties, in turn, always have the potential for unintended consequences when introduced into a new environment, and farming practices in general have a tendency to simplify and destabilize environments, heightening the risk. Additionally, most potential risks associated with GMO crops are no less prone to investigation and mitigation via controlled testing, scientific monitoring, and experimentation than are conventionally

[20] See Avery, as well as Carpenter et al
[21] See Caplan

hybridized crops, and much can be known about potential consequences of GMO use before widespread introduction is carried out.[22]

In sum, the net impact of GMOs on the environment still remains empirically uncertain. Caution is necessary in moving forward with their development and introduction. But in the final calculus it is important to compare the potential for GMO harm with the potential for harm from conventional crops, realizing that conventional farming practices also present environmental risks.[23]

[22] See, inter alia, National Research Council, Food and Drug Administration, and Organization for Economic Cooperation and Development: Final Rapporteurs' Report
[23] Jank, Bernhard and Helmut Gaugitsch

2 NATIONAL POLICIES & GMO IN THE INTERNATIONAL MARKETPLACE

The policy and regulatory realities of GMO development and use are very much in a state of flux. Policy stances in markets that have significant influence over policy decisions in other countries are shifting, meandering, and slowly developing. Thus, there remains a large degree of uncertainty surrounding the future of GMOs and their tradability in international markets. The implications of this have different ramifications for different interest groups, GMO developers such as Monsanto certainly chief amongst them. In keeping with the interests of this investigation however, it is the impacts of the current GMO marketplace on developing countries which we are most concerned with here. Such an analysis necessarily begins with an outline of the current EU/US GMO policy standoff which, incidentally, is rapidly changing. Following this, an overview of other key policy stances in the world sheds further light on how different national policies affect one another and what implications they may have for welfare in developing countries.

2.1 The European / US GMO Policy Standoff

Prior to the advent of mad cow disease (BSE), EU and US regulatory approaches to GMO market release were quite similar[24]. At that time, regulators viewed marketable GMO products as "substantially equivalent" to their conventional counterparts.[25] However the BSE scare of 1996 catalyzed a spike in risk aversion towards GMOs and the subsequent changes in the EU regulatory stance. In October 1998, citing risk and uncertainty, and making use of what is known in international law parlance as the *precautionary principle*, the EU ceased approval of new GMO products[26] and a number

[24] Paarlberg, Robert L. (a) pg 24
[25] Ibid.
[26] International Center for Trade and Sustainable Development (5/14/03)

of EU member states implemented marketing and import bans on GMO products that had already been granted approval for use in the EU.[27]

These actions led to a bitter row between the US and the EU, leading up to the May 2003 official request by the US, Canada and Argentina for WTO consultation. The US request cites violations of the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement), GATT 1994, The Agreement on Agriculture, and the Agreement on Technical Barriers to Trade.[28] At the core of the dispute lay questions about the substantial equivalence of GMO agricultural products as compared to their conventional counterparts, the scientific validity of banning GMOs for *precautionary* reasons, and the degree to which labeling and traceability requirements constitute unnecessary barriers to trade.

At the time of writing, there was considerable chatter in the European Union indicating a probable rollback of what has amounted to a four year moratorium on GMO approval.[29] Indeed, the European Food Safety Authority has recently approved a GM oilseed rape variety for import and processing.[30] But the product joins two other GM varieties that have been granted approval by health authorities and are still awaiting marketing approval from member states,[31] some of which remain doggedly opposed to the any use of GMO in their territories whatsoever. Even disregarding the opposition of EU member states, who may or may not manage to legally ban GMOs indefinitely, a litany of open questions remain. Chief among these is: how stringent final regulations governing GMO standards might be; what effect labeling and traceability requirements might have[32]; how the incidence of liability will fall and what inhibitions this could place on the market;

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[27] International Center for Trade and Sustainable Development (5/14/03)
[28] World Trade Organization: Request for the Establishment of a Panel by the United States; WT/DS291/23 August 8, 2003.
[29] International Center for Trade and Sustainable Development (1/28/04)
[30] Agra Europe (3/5/04)
[31] Ibid
[32] International Center for Trade and Sustainable Development (7/11/03)

and finally, whether allowances might be made for GMO free zones[33] and how such zones could affect agricultural commodity markets.

Meanwhile, the US is coming under increased pressure to take WTO action against European labeling and traceability regulations expected to take effect in April 2004. The US, in concert with Canada and Argentina, contends that the regulations are too strict and will impact competitiveness in European markets.[34] At the same time, ten European *regions* in Austria, Italy, Spain, France, Germany, Greece and the UK have declared intentions to remain GMO free, calling themselves the 'Network of GMO Free Regions'.[35] On January 28, 2004, the European Commission made statements suggesting the possibility of GMO Free zones, provided that farmers in those areas choose to produce without GMO on a voluntary basis. It is not yet clear how this scenario may play out with regard to the law or the marketplace[36], but there should be little question as to its potential for heightening current tensions.

The UK, for its part, has conditionally approved an herbicide tolerant maize product, but farmers using it will be required to grow the crop under the same conditions as the field trials used to test the product. Furthermore, the farmers must carry out scientific analyses as part of an ongoing assessment plan. Both Scotland and Wales will have to provide individual approval for the product as well. Scotland has already committed to doing so, but has said that it will advise farmers against planting the product so as to keep Scotland GM free. Wales, on the other hand, will not back the approval without a number of additional and further restricting measures, including the finalization of a liability scheme.[37]

[33] International Center for Trade and Sustainable Development (11/14/03)
[34] International Center for Trade and Sustainable Development (3/19/04)
[35] International Center for Trade and Sustainable Development (11/14/03)
[36] International Center for Trade and Sustainable Development (1/28/04)
[37] International Center for Trade and Sustainable Development (3/19/04)

In sum, even while the relative positions of the US and the EU are in a current state of change, there is little reason to expect an easing of tensions or a harmonization of policy in the near future.

2.1.1 A Brief Digression: Legal Treatment Under WTO Law

Given such discord, one might reasonably ask how legal structures, particularly international trade law, affect this scenario. There are a number of important factors in this legal discussion, the details of which become far too complex for any large degree of review herein. Nevertheless, it is worth noting that there are legitimate arguments to be explored on both sides of the dispute. I take the opportunity here to quickly introduce some basic points that serve to inform upcoming discussion. These points also illustrate that, given the nuances of particular circumstances, the law could reasonably be expected to come down on either side of the question.

A legitimate pro-GMO argument might proceed as follows: WTO law prohibits unequal treatment of two products in a single market if the products are "like products".[38] Under very reasonable interpretations of what has come to be known as the "product process distinction"[39], one is not hard pressed to argue that a GMO product and its conventional counterpart are like products, provided that the GMO has been scientifically shown to present no risks to humans or the environment beyond those posed by the conventional crop.[40]

A legitimate counter argument makes use of the "precautionary principle", which allows states to ban actions or goods within their territory if they fear that such actions or

[38] General Agreement on Tariffs and Trade Article III
[39] The *product process distinction* has emerged as a fundamental tenant in WTO law which states that regulatory distinctions are to be made for product categories, and not for production methods. In other words, it is permissible to regulate a *category* of products however a state sees fit, but it is not permissible to differentiate among products within a given category based on the production process used to make a particular product within that category.
[40] I have made this argument in considerable detail in a paper fulfilling course requirements for ILO 240, Legal and Institutional Aspects of International Trade. This paper can be made available upon request.

goods may pose danger to human health or the environment – an argument commonly used to prevent the introduction of GMOs. But this allowance for precaution is not without limitations. The WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) stipulates in Article 5 that "In the assessment of risks, Members shall take into account available scientific evidence." In the spirit of precaution, it allows that "where relevant scientific evidence is insufficient, a Member may provisionally adopt…measures on the basis of available pertinent information." But the article tempers this allowance by stipulating that "in such circumstances Members shall seek to obtain the additional information necessary…", thus requiring invokers of the precautionary principle to continue scientific investigation until the question at hand is adequately proven one way or another.[41]

One could readily argue that ongoing scientific investigation is being carried out in parts of Europe,[42] thereby upholding the final stipulation of the allowance for precaution. However, given the degree of understanding that many in the science world claim to have over the few commercially available GM crops currently used, it remains debatable as to whether or not "scientific evidence is insufficient" to a degree that justifies a precautionary ban of these particular crops. In its recent approval of the GM oilseed rape (discussed above), the European Food Safety Authority quoted a European scientific panel's conclusion that the product is "as safe as conventional oilseed rape."[43] Yet some EU member countries hope to prevent the adoption of the product, ostensibly on grounds of precaution[44].

Because there has been no WTO legal treatment of such issues as of yet, it is difficult to know precisely how the law would come down here. Nevertheless, all else

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[41] WTO Agreement on the Application of Sanitary and Phytosanitary Measures, Article 5: Assessment of Risk and Determination of the Appropriate Level of Sanitary or Phytosanitary Protection.
[42] See, for instance Jank, Bernhard and Helmut Gaugitsch; or Burke "Farmscale Evaluations"
[43] Agra Europe (3/5/04)
[44] Ibid.

being equal, it seems unreasonable to expect an allowance for a precautionary ban on a product that has been deemed "as safe as" its conventional counterpart, particularly when that judgment is coming from the scientific authorities within the greater community that seeks to invoke the precaution.

2.2 The Wider Influence of Policy Tides

If the discord between the US and EU were limited strictly to these two entities, one could cynically chalk it up to greed and protectionism amongst rich countries and leave it at that. But the difference of position in fact carries significant implications in many other parts of the world, particularly when one takes other polarized market forces into consideration. For instance, the hard line that Japan now takes on GMO restriction has vast implications for Asian agricultural commodity markets, while Argentina's adoption of GMO soybeans has put it in a very similar position vis-à-vis Korea as the US is now in vis-à-vis the EU.

As noted earlier, the vast majority of commercially available GMO crops are produced in only six countries. However, many other countries legally allow for the use of some GMOs and field trials of others. Nevertheless, there is a tendency for many of these countries to remain largely GM free even if there are legal allowances to use GMO crops[45]. Some suggest that this tendency is strictly for purposes of biosafety. Yet others insist that the tendency is a function of efforts to maintain access to large agricultural import markets, particularly Europe and Japan.[46]

One of the key stumbling blocks that has arisen between GMO agricultural production and these export markets is concern over the commingling of GMO and non-GMO goods in food supplies. The issue harkens back the 'StarLink' corn incident of

[45] For details of particular country policies, see Baumuller
[46] Paarlberg, Robert L. (a)

September 2000,[47] when the GM corn variety, which was approved for animal feed but not human consumption, was found mixed amongst corn for human food use. The incident affected every corn farmer in America, even those who did not produce the GM product, because US corn exports suffered dramatically. Indeed, exports to Japan slid 44% by the following April, and in 2003 the vice-president of the North American Millers Association said that traces of StarLink were still being found in corn shipments almost daily.[48]

Certainly, if an event of this magnitude can occur in the United States, where storage and distribution networks are ostensibly well managed, there seems ample reason for concern that similar events could occur in less well managed networks of developing countries. This, combined with expected or already established labeling and traceability requirements in European, Japanese, and other important markets, provides many potential GMO exporters ample incentive to forego the risk of commingling by simply foregoing the use of GMOs altogether.[49] The unfortunate reality of such a result is that, by default, it affects all GMO products, not just those GMOs that are not authorized for human consumption.

This and similar scenarios have since been played out with a good deal of gusto. China, which actively embraced GMO development in the mid to late 1990s dramatically reduced its GMO activity after witnessing a significant drop in Japanese and Korean imports of US corn. GM soybeans have also been avoided in China so as to provide a ready alternative to US and Argentine soybeans for import in Korean and European markets.[50]

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[47] Ibid
[48] Californian's for GE-Free Agriculture
[49] Paarlberg, Robert L. (a)
[50] Paarlberg, Robert L. (a)

Thailand, like China, initially embraced GMOs but has since retreated, not only restricting the release of GM products for commercial use, but in fact ceasing all GM experimentation and banning imports so as to prevent any potential concern over commingling with important agricultural commodities. Malaysia has had very similar experiences – the country once perceived GMO as a key to future agricultural productivity, but has since held back on commercial releases.[51]

In sum, it cannot yet be said for certain what path international GMO markets will ultimately take. There is no doubt that precaution in advancement is wise, and countries that cannot guarantee the integrity of their segregation between GM and non-GM crops may be wise to forego any risks by eliminating the potential for commingling altogether. But on the flipside, to the extent that GMOs present potential net benefits to their users, there is an undeniable potential for opportunity costs posed by indiscriminately projecting concerns associated with unproven GMO products onto GMO products the safety of which is very well understood. That is to say, as scientific proof of the safety of a particular GMO becomes established, potential users of that GMO incur a cost if regulations that restrict as of yet unproven GMOs also, by default, restrict the proven GMO. Broadly restrictive policies such as blanket labeling and traceability requirement for all GMOs, despite their degree of determined safety, have precisely this capacity to impose costs on potential users. Similarly, so long as anti-GMO pressure groups exert a stronger influence on policy decisions than does scientific proof, similar costs are imposed.

2.3 GMO and Non-Market Concerns of Developing Countries

Discussion thus far has been a prelude to the central question of importance in this investigation, namely preferences toward GMO associated risk and how that risk

[51] Ibid

measures up to the potential benefits that can be derived from GMOs. While many of these potential benefits may hold particular value to developing countries (see section 1.2), GMOs may also pose very particular, and sometimes more severe risks to developing countries than they do to developed countries. To the extent that this is the case, one must include such limitations in the calculus of determining optimal GMO policies for developing countries.

Without going into detail with regard to these risks, I should like to introduce several considerations that should remain on the radar screen. First, the argument has been made that because developing countries tend toward vastness of biodiversity, any threat to biodiversity posed by GMOs is of more significance in these countries because, quite simply, they have more to lose.[52] Second, in so far as a given GMO may cause health complications, such as allergenicity, the limited health care capacities of developing countries constitute an incentive to avoid consumable GMOs that are not known with certainty to have little or no risk of such complications. Likewise, as long as concerns over commingling remain important in certain import markets, developing countries might find their monitoring and management capacities to be inadequate for instilling confidence in those markets.

Finally, we must note the importance of labor intensive agriculture in providing livelihoods to rural farmers in developing countries. This factor could conceivably influence the calculus in either direction. If the GMO reduces the cost or quantity of agricultural inputs required to ensure a reliable harvest, then returns to farmers may increase. However, if the GMO increases overall outputs, then under certain market conditions commodity prices could drop and returns to farmers would be reduced. Currently, commercially available GMOs tend toward the former and by some accounts

[52] Kaushik, Atul. Pg 2

are in fact failures with regard to the latter.[53] Thus, within this context, it does not appear as though currently available GMOs are posed to undermine important commodity markets. Nevertheless, some studies have shown that GMOs do result in yield increases, particularly in regions where pest are highly problematic and not readily controlled.[54] Furthermore, the practical limitations of GMO potential are ill defined and there is no reason to believe that future generations of GMO products will not result in higher yield rates. In sum, it remains quite plausible that GMO use could result in the overproduction of commodities, resulting in price declines.

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With this background established, our investigation now changes gear so as to investigate a particular element of the discussion as hand. In the following section we embark on an in depth review of risk analysis and preferences toward risk. The intention here is to establish a framework in which we can begin to understand how varying perceptions of GMO risk affect the trade of GMOs in international markets. Following this, the final section of the paper draws on previously discussed issues and externally derived empirical analysis to bring the following section's insights to bear on the larger question of GMO risks and benefits.

[53] See, for instance, Qaim and Zilberman. The authors, in arguing that GMOs can in fact increase yields cite many studies showing that GMOs do not have a tendency to increase yields. Clearly, it is not yet certain what the net effects will be. Nevertheless

[54] Ibid

3 ANALYZING RISK

Risk, in the simplest of terms, is uncertainty with regard to the outcome of an action or decision. Treatment of risk in the economic literature is vast, technical, and at times overwhelmingly complex. Nevertheless, even at the most fundamental level, the economics of risk can provide a useful framework within which to consider our query into the relative merits of pursuing versus avoiding the development and use of genetically modified agricultural products.

We begin with a discussion of expected utility and the von Neumann-Morgenstern expected utility function. This framework, in addition to establishing a set of parameters that enter the decision making process when faced with risk, leads us to a very useful representation of attitudes towards risk, which can be mapped through an actor's utility function. The framework also allows us to derive a representation of the *risk premium*, which can be alternatively interpreted as the price of risk or the requisite compensation that an actor requires in order to willingly shoulder a given risk, given that actor's attitude toward risk. Finally, identifying the price of risk allows us to begin asking questions about what ultimately determines this price, which in turn allows us to ask about the accuracy of any particular price associated with any particular risk.

3.1 Utility and the Expected Utility Function

Uncertainty in the development and use of GMOs can be modeled in a standard economic manner, making use of the von Neumann-Morgenstern expected utility theory. This function is specified over four parameters and a number of technical assumptions founded in the theory of rational choice.[55] Herein, I introduce the four parameters in the context of the question at hand; the technical assumptions however, I will leave to those better versed than myself.

[55] Hirshleifer, Riley (1979) pg 1377-1381

1) **Actions:** An actor can choose to engage in any one of the actions contained in the set of possible actions $a = (1,\ldots,A)$. For our purposes, we can consider a country choosing whether or not to develop and make use of (or pursue) genetically modified agricultural products. Thus the set of two possible acts (pursue *p* or not pursue *np*) is $a = (p, np)$.[56]

2) **Expected states of the world:** This refers to a probability function expressing the likelihood that the world will be in any one specific *state of nature* at the time that the consequences of the above chosen action come to bear. Thus, if there were three possible states of nature with regard to the pursuit of GMOs (ie, s_1, s_2, and s_3, corresponding to: GMOs cause net harm to humans and the environment, GMOs have no net impact on the world, and GMOs yield net benefits to humans and the environment), each of those states of nature might emerge with probability π_i (such that $\pi_i < 1$, and $\pi_1 + \pi_2 + \pi_3 = 1$).[57]

This representation assumes that the relative probabilities of each outcome are known, or at least believed to be known, by the actor at the time the decision on how to act is being made. In many applications of expected utility theory, this is not an unreasonable assumption (take for instance life insurance, in which actuarial tables can provide reasonable estimates of life expectancy, given certain information about an individual's health and lifestyle). Nevertheless, in the context of assessing the risks versus benefits of GMO use, a lack of historical knowledge as to how the introduction of these genetically unique organisms will affect humans and the environment is largely unknown, thus revealing a crux of the problem at hand. At present, I will assume a generally specified probability

[56] Ibid. 1377
[57] Ibid. 1378

function, but we must recognize the limitations that this issue imposes on our analysis.

Of the four parameters defining the von Neumann-Morgenstern expected utility function, it is this parameter that explicitly represents the risk being faced. This is so because even if the probabilities of each possible state of the world are known with absolute certainty, there still remains the possibility that the most undesirable state of the world will emerge.

3) **Consequences of an action in a given state of the world:** This is defined by yet another function (the consequence function) which defines the actor's state of existence, ex-post, given any action and the state of nature that happens to emerge at the relevant time. Thus, the function *C(a,s)* is defined to show specific outcomes under all possible combinations of *a* and *s*.[58]

For our purposes, the consequence function can be defined to reveal some measure of the country's wellbeing ω after making a decision to pursue or not pursue GMO development and learning, at some point in the future, the net impact that GMO use had on humans and the environment. If, for instance, a country chose to pursue GMO development and in time it was learned that GMOs yield a net benefit to society, then we could say that $C(a,s) = \omega_{high}$. Similarly, pursuing GMOs and later learning that they yield a net harm would result in $C(a,s) = \omega_{low}$. Alternatively, choosing not to pursue GMOs but later learning GMO use yields net benefits would result in some value $\omega < \omega_{high}$. Similarly, choosing not to pursue GMOs and later learning that they cause net harm would result in some value $\omega > \omega_{low}$. In fact, if there is no subjective discount factor associated with the opportunity costs of not pursuing GMOs in a state of the world where it is

[58] Ibid. 1379

ultimately revealed that GMOs are beneficial, then for any country that chooses not to pursue GMOs, the resulting ω would be equal to the ω that prevailed prior to the decision to pursue or not pursuer GMOs, irrespective of which state of the world prevails. That is, nothing ventured, nothing gained, but nothing lost.

Because it is uncertain what value ω will emerge, we call ω a random variable. The randomness of ω is yet another way of recognizing the presence of risk in this model, but this is not distinct from the risk identified in our discussion about *Expected States of the World,* because it is the probability distribution function identified in that discussion which ultimately governs what value of ω emerges.

4) **The actor's utility function:** Utility is explicitly associated with both *a* (the actor's choice of action) and *C* (the consequences of that action, given a specific *a* and *s*). To be more specific, a particular action *a* is selected based on which action will maximize utility *u*(*a*). This value *u*(*a*), in turn, is determined by finding a weighted average of the utility associated with each *C(a,s)*, where the weights of the average are defined by the corresponding π value, or the probability that this *C* will arise.[59] The resulting *u*(*a*) is known as the *expected utility* and can be denoted *eu*(*a*).

Building on the present example where the possible actions (to pursue GMO or to not pursue GMO) are represented by the set *a = (p, np)*, the possible states of the world (GMOs cause net harm to humans and the environment, GMOs have no net impact on the world, and GMOs yield net benefits to humans and the environment) are represented by the set $s = (s_b, s_{n\Delta}, s_g)$, and these possible states of

[59] Ibid. 1379

the world will emerge with corresponding probabilities π_b, $\pi_{n\Delta}$, *and* π_g,[60] the resulting expected utility functions for $a = p$ and $a = np$ will be the following:

$$eu(p) = \pi_b \cdot u[C(p, s_b)] + \pi_{n\Delta} \cdot u[C(p, s_{n\Delta})] + \pi_g \cdot u[C(p, s_g)]$$

and

$$eu(np) = \pi_b \cdot u[C(np, s_b)] + \pi_{n\Delta} \cdot u[C(np, s_{n\Delta})] + \pi_g \cdot u[C(np, s_g)]$$

More generally, the expected utility function for any action a_i can be written:

$$eu(a_i) = \pi_{s1} \cdot u[C(a_i, s_1)] + \ldots + \pi_S \cdot u[C(a_i, s_S)] \qquad (3.1)$$

$$\text{for all } s = (s_1, \ldots, S) \text{ where all } \pi_s < 1 \text{ and } 1 = (\pi_{s1} + \ldots + \pi_S)$$

In sum, this basic representation of the von Neumann-Morgenstern expected utility theory states that an actor who must make a decision under uncertainty will choose between a variety of actions based upon which action yields the highest expected utility. This expected utility in turn is the result of a well defined utility function, a well defined consequence function, and a knowledge of the probabilities with which all possible states of the world will emerge. There is reason to be skeptical as to the degree to which these functions and probabilities can be known, particularly with regard to relatively untested technologies such as GMOs. These limitations warrant considerable exploration, and some are discussed to a greater or lesser degree in other parts of this paper. Nevertheless, it goes without saying that the parameters of the von Neumann-Morgenstern expected utility theory are but a rough outline under which to explore this vast and complex question. No earth shattering or definitive results can be expected here, but it is not unreasonable to think that we might be able to present the question in a more structured framework and shed new light upon it.

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[60] Regarding notation: subscript $_b$ = bad (GMOs cause net harm), $_{n\Delta}$ = no change (GMOs have no net impact on the world), and $_g$ = good (GMOs yield net benefits).

3.2 Preferences For Risk: A Graphical Representation of Utility and Expected Utility

Preferences toward risk lie at the heart of the question at hand, in that some countries' aversions to GMOs might be explained, at least in part, by an aversion toward risk.[61] The economic literature often discusses risk aversion vis-à-vis its polar opposite, risk seeking. These preferences for risk can be mapped directly into the above discussed expected utility function but altering the functional form of *u*(•); a concave function expresses risk aversion while a convex function expresses the opposite, as is illustrated in Figure 3.1.[62]

Figure 3.1: Expected Utility for a Risk Averse and a Risk Seeking Actor

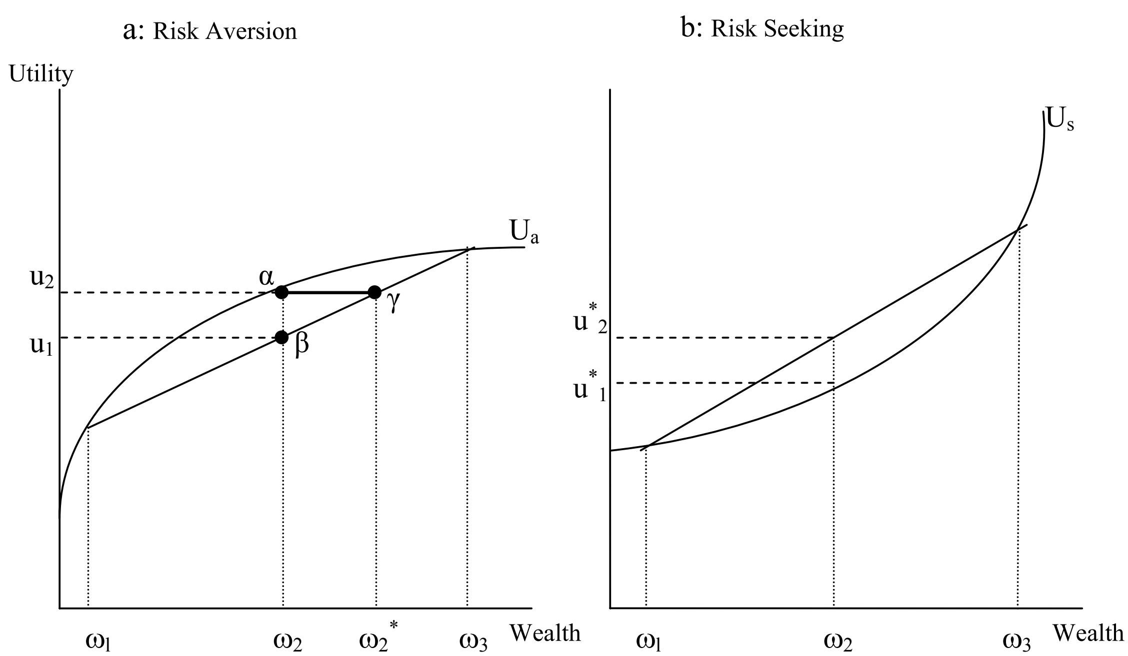

Figure 3.1 corresponds to a *lottery* in which an actor has a 50% chance of receiving ω_1 and a 50% chance of receiving ω_3 where $\omega_1 < \omega_2 < \omega_3$. The expected value

[61] In fact, many commentators speculate that recent food safety scares such as mad cow disease and foot and mouth disease are in part responsible for creating a general aversion toward any food safety related risks in Europe. See, for instance, Paarlberg, Robert L. (a).
[62] Pindyck and Rubinfeld pg 158

of this lottery is $0.5(\omega_1) + 0.5(\omega_3) = \omega_2$.[63] The expected value, however, is quite distinct from the expected utility. This relationship is illustrated by points α and β, and their corresponding utility levels, in Figure 3.1a. Point α represents the mapping between the expected value of the lottery and the utility that can be derived from this expected value, u_2. This utility level u_2 is a function of the actor's utility function U_a evaluated at the expected value of the gamble. However this mapping does not take into account the actor's distaste for risk. The expected utility function, $0.5[U_a(\omega_1)] + 0.5[U_a(\omega_3)] = U_a(\omega_2)$, does take this risk aversion into account, corresponding to the utility mapping through point β and resulting in utility level u_1. Because the actor's utility function U_a is concave (suggesting that as wealth increases, the utility associated with that wealth increases by less and less), the utility associated with β is necessarily less than that associated with α.[64]

We should also take note of the relationship between points α and γ, and the corresponding values of ω_2 and ω_2^*. The distance between points α and γ is the *risk premium*, or the value $\omega_2^* - \omega_2 = \mathfrak{R}$. The risk premium is the additional wealth that would have to be provided to the actor in order to entice her take on the risk associated with the gamble; that is, $\mathfrak{R}$ is the additional wealth needed to bring the actor to the utility level associated with the expected value of the gamble, thereby compensating the actor for risk entailed in the gamble.[65]

Figure 3.1b illustrates the opposite scenario, in which a risk seeking individual is shown to gain more utility from taking on a gamble than would be gained strictly as a result of acquiring the expected value of the lottery. Note, however, in this instance, that

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[63] Adapted from Varian, Hal R. (a) pg220-224
[64] Ibid.
[65] Adapted from Pindyck and Rubinfeld pg 158

the expected value of ω_2, u^*_1, is in fact less than the expected utility of ω_2, u^*_2, ostensibly because the actor garners some additional utility by virtue of undertaking the gamble.[66]

3.2.1 Preferences For the Risk of GMO Use: A Conjectural Application

It is tempting to consider attitudes toward the risks associated with GMO use in the context of the above discussion. After all, while it is unlikely that attitudes toward risk can fully account for the difference of opinion between the GMO averse and the pro-GMO nations, it seems apparent that attitudes towards this particular risk vary, at least at the level of public policy. (For clarity, the reader should realize that throughout this section, when discussing risk aversion, I am speaking strictly about aversion to the risks associated with the use and development of GMOs, and am making no judgments with regard to other risks borne out in the societies in question).

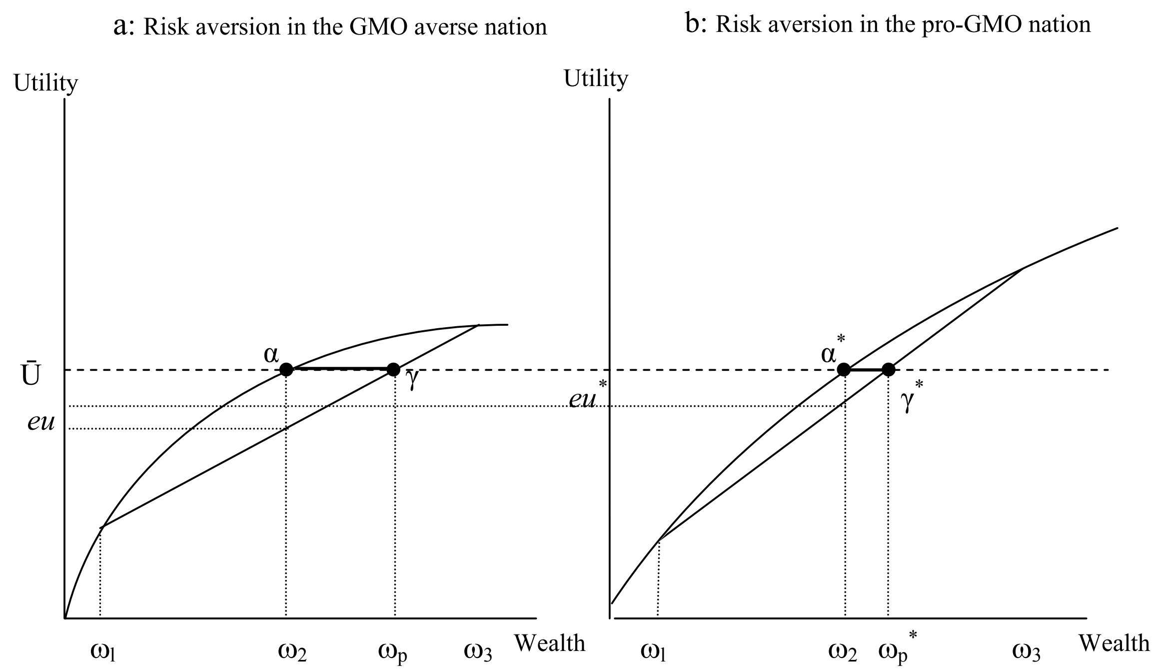
While we are interested in comparing attitudes toward risk, adhering to the strict dichotomy between risk aversion and risk seeking illustrated in Figure 3.1 above seems rather disingenuous. It would, I believe, be a significant misrepresentation to suggest that pro-GMO nations seek out, and in fact increase their utility by taking on the risks presented by GMO use. After all, GMO development is subjected to a high degree of regulatory scrutiny.[67] Of course, reasonable people might readily disagree on whether or not the current level of scrutiny is adequate, but I feel it is reasonable to conclude that the degree of scrutiny demonstrated is antithetical to the supposition that GMO development is characterized by a wanton display of risk seeking behavior.[68]

Rather, it is more instructive to compare GMO averse nations and pro-GMO nations in terms of the *degree* to which they display risk aversion. To illustrate, let us

[66] Adapted from Varian, Hal R. (a) pg220-224
[67] See for instance: The National Research Council *Environmental Effects of Transgenic Plants: The Scope and Adequacy of Regulation.*
[68] This assumption of risk aversion in both GMO averse and pro-GMO nations is also in keeping with the general assumption made throughout the economic literature that actors are, for the most part, risk averse.

conjecture that while both types of countries are risk averse, GMO averse countries are *more* averse to the risks presented by GMOs than pro-GMO countries. That is to say, the utility curve of the GMO averse nation is *more* concave than that of the pro-GMO nation. Such a comparison is illustrated in Figure 3.2, where the expected value ω_2 yields the same utility, $\bar{U}$, for both countries, and the pro-GMO country enjoys a higher expected utility (*eu**) than the GMO averse country (*eu*).

Figure 3.2: Comparative Degrees of Risk Aversion



A particularly instructive aspect of Figure 3.2 is the relationship between points α and γ in diagram *a*, vis-à-vis the relationship between α^* and γ^* in diagram *b*. The reader will recall that this relationship was introduced in Figure 3.1 and labeled the *risk premium*. In diagram *a*, the GMO averse nation's risk premium is shown to be greater than that of the pro-GMO nation in diagram *b*. This result can be precisely quantified as $(\omega_p - \omega_2) > (\omega_p^* - \omega_2)$. Because the value ω_2 is the same in both diagrams, this shows that the GMO averse nation assigns a higher premium to the risk associated with GMO development and use than does the pro-GMO nation. Stated in terms similar to that in the previous section, in order to compensate the GMO averse nation for taking on the risk of GMO development, it must receive a greater supplement to its welfare than would be required by the pro-GMO nation.

This concept of risk premiums and the compensation required to take on a risk can be cast in an alternative but analogous manner; that is, in terms of the *price of risk*. The diagrams in Figure 3.2, in revealing the risk premiums implied by both types of countries, also reveal the price that those countries place on the risk (in fact, these are two alternative interpretations of the same thing). Consideration of these revealed *prices of risk* allow us to further analyze the current position that GMOs hold in world markets.

3.3 The Price of Risk: An Analogy from Financial Economics

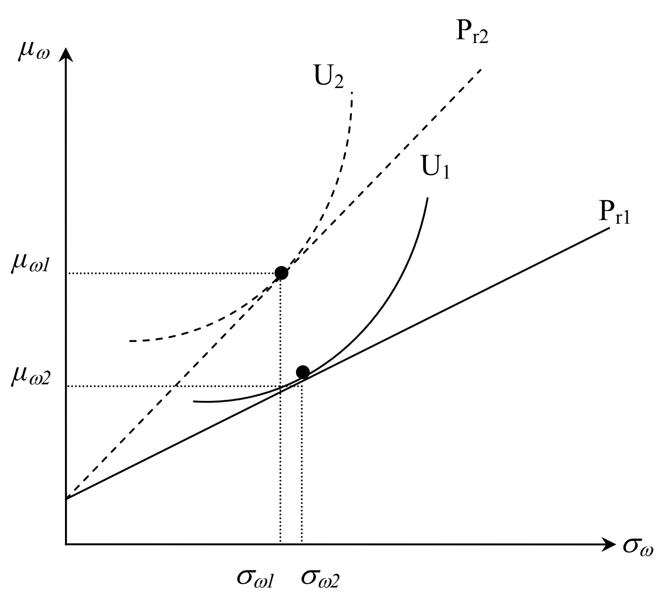
In the previous section, I outlined an approach by which to identify a revealed price of risk. We will now look more closely at the component parts of the price of risk, making an analogy to financial economics. As will become apparent in due time, dissecting the price of risk into its component parts will allow us to look carefully at the causes for concern over the development and use of GMOs, and to ask whether or not the revealed price of risk assigned by GMO averse nations might be overstated.

Financial analysis estimates an actor's utility as a function of the mean and the variance (or standard deviation) of the potential output value of an assumed risk. This is, in many ways, similar to the expected utility model that we investigated earlier, in that it examines the probability that a certain outcome will prevail.

In general form, the utility function is written $u(\mu_\omega, \sigma^2_\omega)$, where ω is still a random variable denoting a measure of wellbeing (as in the previous section), μ is the average value of ω defined over some known probability distribution (analogous to that in the expected utility model), and σ^2 measures the variance, or the average difference in value between any ω_i and the mean value of ω. Because σ^2 (variance) represents the degree to which possible results may vary from one another, it represents risk in this model.[69] An alternative and very similar measure is the standard deviation, which is nothing more than the square root of the variance and denoted by σ; for convenience of notation, I will refer only to standard deviation from here on, but since we are speaking in general terms, this differentiation between variance and standard deviation will have no bearing on our results.

The utility function U=$u(\mu_\omega, \sigma_\omega)$, can be illustrated in a simple two dimensional space with μ_ω on the vertical axis and σ_ω on the horizontal axis (see Figure 3.3). As Figure 3.3 illustrates, an actor with utility function U is able to reach a higher indifference curve when the mean value of her expected outcome rises or the standard deviation (ie, risk of achieving that outcome) falls.[70]

Figure 2.3: Price of Risk as a Function of Outcome and Standard Deviation



[69] Varian, Hal R. (a) pg 230-235
[70] Adapted from Varian, Hal R. (a) pg232-235

More importantly, we can learn from this picture that the price of risk (P_{r1} and P_{r2}) is a marginal rate of substitution between a higher valued outcome and increased risk. That is, for an actor to take on more risk, the expected value μ_{ω} must also increase by a sufficient amount.[71] This pricing structure can be represented by equation 3.2, where some price of risk P is defined as the difference in the amount of risk between a non-risky option r_n (subscript n representing little or no risk) and a risky option r_b (subscript b representing bad risk) divided by the standard deviation of the risky option, σ_{rb}[72].

$$P = \frac{r_b - r_n}{\sigma_{rb}} \qquad (3.2)$$

An alternative interpretation of equation 3.2 is to view the value $r_b - r_n$ as the *incremental risk* associated with ceasing the action giving rise to risk level r_n and initiating the action giving rise to risk level r_b; that is, the incremental risk is equal to $r_b - r_n$.

Thinking in terms of incremental risk is quite convenient for our purposes because we can now consider the incremental risk between the use of GMOs and the use of their conventional counterparts. To be more specific, the conventional counterpart of a genetically modified agricultural product such as *Bt* Corn would be any of a variety of conventionally hybridized corn species commonly used by farmers in a given region. As has been discussed previously, and as will be further discussed in the next section, scientific opinion has much to say about the incremental risk between conventionally hybridized and genetically modified crops. This opinion, in turn, suggests something about the real price of risk associated with the development and use of GMOs.

[71] Ibid.
[72] Ibid.

3.4 The Implied Price of GMO Risk: Scientific vs. Perceived Risk

We saw in section 3.2.1 that an aversion to risk implies a *risk premium*, and that an actor more averse to a particular risk than another actor will require a higher risk premium if she is to accept that risk. Figure 3.2 suggests that GMO averse nations will assign a higher risk premium to GMO development and use than will pro-GMO nations. Given that the risk premium is analogous to the price of risk, we can now look at the component parts of the price of risk, as defined in the previous section, and consider the degree to which they are accurately perceived by GMO averse and pro-GMO nations.

The first step is to restate equation 3.2 in two separate equations. The first equation, 3.3, shows the price of risk associated with conventional crops, P_{con}, based on the incremental risk between conventionally hybridized agricultural products, r_{con}, and some hypothetical food production methodology that is believed to be risk free, r_f.[73]

$$P_{con} = \frac{r_{con} - r_f}{\sigma_{con}} \tag{3.3}$$

The second equation 3.4 is analogous except in that it pertains to GMOs.

$$P_{gmo} = \frac{r_{gmo} - r_f}{\sigma_{gmo}} \tag{3.4}$$

The next step is to look critically at the variables r_{con}, r_{gmo}, σ_{con}, and σ_{gmo}, to determine their relative values vis-à-vis one another. To do this, we need to appeal to current scientific opinion. This broad and complex topic has been touched on elsewhere in this paper, but I will revisit several fundamental strains of the discussion, so as to put the importance of our risk pricing model into perspective.

[73] The reader might be inclined to believe that conventionally hybridized crops should bear the same risk as the hypothetical "risk free" crop, thereby making this measure of incremental risk unnecessary. However, as is discussed on a number of occasions throughout, conventionally hybridized crops, like GMOs have the potential to pose risks to human health and the environment.

According to the National Research Council (NRC), "both transgenic and conventional approaches to adding genetic variation to crops can cause changes in the plant genome that result in unintended effects on crop traits."[74] Furthermore, all farming practices "exert simplifying and destabilizing effects on neighboring ecosystems" which have the potential to weaken or destroy the ecosystem's resilience. Therefore, both GMO crops and non-GMO crops that bear novel genetic traits have heightened potential to cause adverse ecological effects. This suggests the need for "a cautious approach in the release of any crop that bears a novel trait."[75]

Similarly, risks to human health, while of considerable importance in the GMO debate, are not beyond the purview of modern scientific investigation. Like the NRC, the US Federal Drug Administration finds that "virtually all breeding techniques, not just those involving novel DNA, have the potential to create unexpected food safety effects."[76] Changes in known toxicants, changes in nutritional levels, and changes in the potential for allergenicity are all recognized as potential results of both GMO and non-GMO crop breeding processes, each of which can be monitored and controlled for via modern scientific investigation and experimentation. The possible introduction of new substances, unlike the above mentioned risks, is in fact unique to GMOs, but such changes are neither, *a priori*, positive or negative with regard to food safety[77].

Concluding assessments of the NRC's report "Environmental Effects of Transgenic Plants" represent the general scientific consensus on the relative risks of GMO and non-GMO crop enhancement methodologies: "The transgenic process presents no new categories of risk compared to conventional methods of crop improvement

[74] NRC pg 5
[75] Ibid
[76] Nelson and De Pinto
[77] Ibid

but…specific traits introduced by both approaches can pose unique risks."[78] Lest the reader conclude that such assessments are the product of a bias in US interests, consider the conclusions of two Austrian researchers, Jank and Gaugitsch, who state "it is too simplistic to talk about the impacts of genetically modified crops without comparing their impacts with those posed by conventional practices."[79] Also consider an October 2003 open letter to UK Prime Minister Tony Blair, signed by over one hundred British scientists, claiming that British consultations over GM policy had been highly distorted by anti-GMO interest groups and criticizing the government for not correcting false claims about GMO in the media.[80] Finally, note a Farmscale Evaluation (FSE) completed by the UK's Department for Environment, Food and Rural Affairs (DEFRA) in October 2003. The FSE assessed the impact of three GMO crops on certain aspects of the surrounding ecosystem and compared the impact to that of the crop's conventional counterparts. Results showed that two of the crops, herbicide tolerant sugar/fodder beet and herbicide tolerant spring-sown oilseed rape, had negative implications for the surrounding ecosystem, while the third crop, herbicide tolerant maize, had positive implications.[81]

This discussion no doubt delves into controversial territory, but what is of considerable importance for our discussion here is that the NRC assessment suggests the possibility that the variables r_{con} and r_{gmo}, and σ_{con} and σ_{gmo} in equations 3.3 and 3.4 may, in some circumstances, be quite similar in value respectively. Building on this, if we accept for the moment that $r_{con} \approx r_{gmo}$ and $\sigma_{con} \approx \sigma_{gmo}$, then because the value r_f is the same in both 3.3 and 3.4, it follows that $P_{con} \approx P_{gmo}$. This is not to say that there is no risk associated with the use of GMOs, rather it says that there may be little or no incremental risk between conventionally hybridized crops and GMOs. If this is true, then foregoing

[78] NRC pg 5
[79] Jank, Bernhard and Helmut Gaugitsch
[80] BBC News Online
[81] Burke, "Farmscale Evaluations"

the development and use of GMOs en masse seems unwise if GMOs promise some potential for benefits that exceed the total benefits to be derived from conventional crops.

For the sake of argument, allow me, for the time being, to continue to accept the above stated approximate equalities and the supposition $P_{con} \approx P_{gmo}$. Given this, how might we account for the noted discrepancy in the price of risk between GMOs and conventionally hybridized agricultural products? I suggest that the overstated price of risk in GMO averse nations is the result of *perceived risk,* which may very well be greater than the *scientific risk*.

A fundamental problem that this investigation faces, of course, is that neither the perceived nor the scientific risk can be measured directly. But as is argued in other sections of this paper, an overstated price of risk (to the extent that it exists) imposes costs on those countries most likely to garner incremental utility from the potential benefits of GMO development and use. I suggest that developing countries, to the extent that they have much to gain from the more optimistic potentialities of GMOs, therefore bear the highest impact associated with an inflated price of risk.

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Before progressing to the next stages of this discussion, it is worthwhile to investigate an alternative approach to risk pricing, making use of insurance markets. This discussion is somewhat heuristic, in that I am not aware of any markets currently providing insurance against ill affects of GMO use. It nevertheless illustrates a method by which an objectively determined price of risk can be determined. In time, as the risks of particular GMO products are better understood, such pricing may begin to offer important insights to the core issues investigated in this paper.

3.5 An Objective Price of Risk: What Insurance Markets Could Tell Us

Market efficiency, as a main underpinning of modern economic thought, is believed to reveal accurate prices under assumptions of pure competition. Thus, in our search for an accurate statement on the price of GMO risk, we might look to markets that competitively buy and sell risk; that is, the insurance market.

If we assume that a competitive insurance market with free entry and exit exists in which risk averse producers of GMO products can buy insurance against the possibility that their products will have some adverse effect on humans or the environment, and if we further assume away the possibility for moral hazard[82], then we can expect such an insurance market to reveal a price of GMO risk that accurately represents the scientific risk. Why, we might ask, should it be that an insurance market will reveal a more accurate price of risk than that which is suggested in Figure 3.2? Because an actuarially fair insurance premium, determined under perfect information and without the risk of moral hazard, will be based purely on the probability of loss and the value of loss expected. It will not be confounded by misinformed perspectives on the risks of GMO, because inflated prices based on misinformation are precisely analogous to overpricing in any competitive market, and as we know, the theory of microeconomics predicts that such inflated prices will be bid down by new entrants to the market seeking to acquire a portion of the profits.

Consider the von Neumann-Morgenstern expected utility function discussed in section 3.1. Let us now restate that equation in terms of the expected utility of an actor who has chosen to develop and make use of GMOs. This actor regularly enjoys an

[82] These assumptions: (1) competition in the insurance market (2) that the consumer of insurance cannot effect the probability of loss (ie no potential for moral hazard) and (3) the consumer of insurance is risk averse (as we assumed in figure 2.2), are necessary in order to achieve actuarially fair insurance premiums. They are adapted from Varian, Hal R. (b) pg 180-181.

income of A, and derives utility U(A) from this income.[83] In choosing to pursue GMOs, the actor faces the probability π that this GMO product will result in some positive net impact X and the probability $1-\pi$ that it will result in some negative net impact $-Y$, where $\pi<1$. Thus, in keeping with equation 3.1, the expected utility associated with the actor's decision to pursue GMO development and use can be written as:

$$eu_{(pursue\ GMO)} = [\pi \cdot u(A+X)] + [(1-\pi) \cdot u(A-Y)] \quad (3.5)$$

If our actor meets misfortune and the net impact of $-Y$ ensues, other members of society who are effected by this negative turn of events will demand reimbursement of the amount Y, which ultimately must come from our actor's initial income, A.[84]

If our actor chooses to venture into the risky world of GMOs without insurance against the possibility of ill effects, her expected utility is precisely as it appears in equation 3.5, revealing the possibility that future utility might emerge as a value less than U(A). However, if our actor chooses to purchase an insurance policy with premium rate P_{ins}, this insurance policy can help to assuage the negative impact of misfortune by promising to pay an indemnity, I, to our actor if ill fortune should emerge. Such an insurance policy can be characterized by the ordered pair (P_{ins}, I), which simply states that our actor must pay a premium of value P_{ins} for an insurance policy that pays an indemnity of value I if ill fortune ensues. After purchasing such an insurance policy, our actor's utility function will appear as:

$$eu(P_{ins}, I) = [\pi \cdot u(A + X - P_{ins})] + [(1-\pi) \cdot u(A - Y - P_{ins} + I)] \quad (3.6)$$[85]

[83] In keeping with our assumption of risk aversion, U(•) is defined as concave.
[84] Adapted from Bierman and Fernandez pg 131-134
[85] It is worthwhile to discuss the implications of several values in 2.6.
First, in this general form, we have not indicated the value of A vis-à-vis X or Y. However this relationship speaks volumes to the impact that GMOs might have on our actor's utility. Let us imagine, for instance, that the value of Y is considerably larger than A; this indicates that A – Y would equal some value –Q, showing that our actor's overall utility has been negatively impacted. If we reconsider this question in a context in which our actor is a country with aggregate utility U(A), then the implications of A<Y is that experimenting with GMOs could have catastrophic consequences for the country in question. Some who

This equation states that our actor's expected utility is based upon two probable values. The first of these is her initial income (A), plus the revenue associated with the successful introduction of the GMO (X), minus the cost of her insurance policy (P_{ins}). The second value is her initial income minus the costs to society of problems caused by the GMO (–Y), minus the cost of her insurance policy, plus the indemnity paid (I).[86]

The insurance company will only provide this insurance policy to our actor if the premium accurately represents the risk that the insurance company undertakes, which is a $(1 - \pi)$ probability of paying indemnity I. If we assume that there are no administrative costs associated with purchasing the insurance policy, then the insurance company's revenue R can be represented as:

$$R(P_{ins}, I) = P_{ins} - (1 - \pi) \cdot I \qquad (3.7)$$

This equation states that the insurance companies expected revenue, or profits, is equal to the insurance premium minus the indemnity times the probability that the indemnity will be paid out to the client.[87]

Because we are assuming a competitive insurance market in which profits equal zero, the insurance company will not be able to demand a premium higher than this accurate representation of the risk, as doing so will simply drive our actor to take her business to another insurer. Therefore we can state that the insurance company's revenues must equal zero, and by simple algebra the premium $P_{ins} = (1 - \pi) \cdot I$.[88]

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weigh in on the GMO debate suggest that this may in fact be the case, while others suggest it is quite improbable. I assume throughout this paper that A>Y.

Second, we have not yet indicated the value of I vis-à-vis the value of Y. Our actor may choose to purchase an insurance policy that will return her to her previously level of A, in which case $I - Y = 0$, or $I = Y$. In such an instance, the resulting utility function would appear as $eu(P_{ins}, I) = [\pi \cdot u(A + X - P_{ins})] + [(1 - \pi) \cdot u(A - P_{ins})]$, suggesting that the only cost to our actor in the event of ill fortune is the cost of the insurance policy, P_{ins}.

[86] Adapted from Bierman and Fernandez pg 131-134

[87] Ibid.

[88] Ibid.

Stated differently, P_{ins} is the risk premium denoted by the distance between points α and γ in figure 3.1, which was later said to represent the price of risk. That is, P_{ins} is the compensation of value ω that the insurance company must be provided in order to accept the risk in question. What remains to be answered is whether or not the value ω determined by the insurance company would be equal to the value ω determined by the GMO averse nation, and if it is not, why we should believe that the ω determined by the insurance company is a more accurate representation of the real price of risk.

The first of these questions cannot yet be answered, particularly because we still do not fully understand the value of π; in other words, we do not know the probability that net benefits versus net harm will arise from the use of GMO use. However the second question can be resolved simply by referring to equation 3.7 and its algebraic alternative $P_{ins} = (1 - \pi) \cdot I$. Notice that the value P_{ins} is purely dependent on the value of the indemnity and the probability that it must be paid. There is no utility function present in this equation, and therefore there is no indication of the insurance company's attitude toward risk. This implies that the insurance company is risk neutral, which is to say that it is only concerned with accurately gauging the likelihood that it will have to pay out an indemnity and how much that indemnity will be. Thus, to the extent that these parameters can be adequately estimated, the insurance company requires a premium that reflects the actual price of risk.

The limiting factor, of course, is the difficulty in measuring the necessary parameters. But in time, as our understanding of GMOs develops further, we may one day be able to accurately judge the price of GMO risk, thereby allowing us to legitimately weigh this risk against the potential for benefits.

4 EMPIRICS

While empirical investigations surrounding GMOs are still few in number, there have been several papers published using a general equilibrium model known as GTAP (Global Trade Analysis Project) to estimate the impacts of GMO use on global welfare. GTAP makes use of a sizable database detailing international trading patterns to estimate the impacts of a particular shock on the world economy. The earliest of the papers reviewed below look specifically at welfare changes associated with productivity shocks caused by the introduction of GMOs. The results are generally consistent with what has been suggested above, but tend to illustrate a higher degree of nuance and detail. A later paper introduces health benefits associated with the use of Golden Rice, and incorporates the reduction of blindness caused by vitamin A deficiency into the global welfare estimations. Once again, the implications are consistent with what has been discussed above. However in this case the authors point out that because of the insulated nature of international rice markets, most countries that could readily benefit from Golden Rice would not be easily influenced by aversion to the GMO product in important export markets. This proves to be of significant import for the potential role of Golden Rice, not only in terms of the possibility for health benefits, but in terms of the potential for furthering the use of GMOs to benefit developing countries.

4.1 GTAP Findings on the International Trade of GMOs

In *GMOs, Trade Policy, and Welfare in Rich and Poor Countries,* Chantal Nielsen and Kym Anderson model global implications of GMO adoption under various policy conditions.[89] Because the primary commercial application of GMOs thus far has been pertinent to maize and soybeans, the earliest GTAP modeling was specific to changes in the cereal grains sector (excluding wheat and rice) and oilseeds sector. The

[89] Nielsen and Anderson (2000a)

corresponding genetic modifications are directed at pest resistance, not increased output, so the sum effect of GMO use is to reduce the cost of production. But because data characterizing such implications is currently scarce, the authors chose to model this impact as productivity growth instead of a reduction in production costs. This is justified by an assumption that GMO adoption results in a Hicks-neutral technology shift, or a uniform reduction in all inputs, and is captured by a 5% increase in productivity that in turn reduces the supply price of the GMO.

The first set of results is based on such a 5% increase in productivity of cereal grains (excluding wheat and rice) and oilseeds. Under assumptions of adequate demand, reductions in production cost lead to increased factor returns in the GMO adopting sectors. Factors of production therefore relocate appropriately. If demand conditions are not sufficient, however, prices might decline so much so as to reduce profitability and returns to factors of production as supply rises; these scenarios are not modeled based on the current GTAP database, but they are a possibility under unanticipated conditions. Naturally, other sectors in the economy experience changes as well due to vertical and horizontal linkages; GTAP captures these effects.[90] (Due to the nature of GTAP, countries are aggregated into regions and products are aggregated into sectors – the implications for real world representation are, I believe, self evident.)

Nielson and Anderson investigate four scenarios in this paper. The scenarios are defined here and results are summarized in table 4.1.

Scenario 1: Widespread adoption of GM maize and soybeans in North America – no other regions adopt

Scenario 2: Scenario 1 + adoption in Mexico, the Southern Cone region of South America, India, China, East Asia's other lower-income countries, and South Africa (remaining African Countries are assumed incapable of adopting the technology)

[90] Ibid

Scenario 3: Scenario 2 + Western Europe bans the import of all GM oilseeds and cereal grains via a costless requirement to label all products from GM producing countries as "may contain GMOs" – all agricultural products with such labels are turned away at the border

Scenario 4: Rather than an all out ban as in scenario 3, scenario 4 consists of scenario 2 + Western European consumers shift preferences away from imported cereal grains and oilseeds that may contain GMOs, and substitute into domestic substitutes – (this scenario is implemented in the model as a 25% reduction in demand for imported oilseeds and cereal grains; it corresponds to the real world scenario in which European GMO bans are determined to be GATT illegal and consumers thereafter express preferences through their market purchases – notice however that the impact on imports is merely one fourth of the impact in the previous scenario)

Table 4.1: Results from *GMOs, Trade Policy and Welfare in Rich and Poor Countries*[91]

	Results
Scenario 1	▪ North American cereal production rises by 3% and oilseed production rises by 7% ▪ World prices of cereals decline by 2.5% and oilseeds by 1.6% ▪ Production of both commodities declines in all other regions due to intensified competition from North America ▪ Global welfare (measured in equivalent variations of income) increases by $5.5 billion per year, half of which accrues to North America ▪ Most of the remaining welfare increase accrues to Western Europe and other high-income countries – a small portion of this is due to cheaper inputs while a greater portion is due to a movement of resources out of protected agricultural sectors
Scenario 2	▪ Due to increased competition (Particularly from the South American Southern Cone Region), North American production increases are less than in scenario 1 ▪ In the South American Southern Cone Region, oilseed production increases by 5% and exports increase by 10.5% ▪ World prices of cereals fall by 4% and oilseeds by 4.5% ▪ All regions (both adopting and non-adopting) gain welfare except Sub-Saharan Africa (which is assumed not to have the capacity to adopt the new technology) ▪ World welfare increases by $9.9 billion per year – nearly double that of scenario 1 ▪ Approximately half of these gains accrue to developing countries
Scenario 3	▪ Due to high North American dependence on Western European markets, North American oilseed exports decline by 30% and production declines by 10% - resources leave this sector, despite the fact that productivity has risen due to the technology ▪ North American cereal markets are also impacted, but less severely ▪ Other adopting regions are impacted similarly to North America ▪ Sub-Saharan Africa, still assumed unable to adopt the technology, gains access to Western European markets as other competitors are excluded – oilseed production increases by 4% ▪ Western Europe increases production of oilseed and cereals, drawing resources from other sectors and increasing costs for downstream users of cereals and oilseeds, causing prices to rise ▪ Western Europe aggregate welfare declines by $4.3 billion per year, primarily due to inefficiency of resource allocation ▪ All other regions gain welfare, but reduced from that under scenario 2 (Continued on next page)

[91] Nielsen and Anderson (2000a)

	▪ World welfare rises by only $3.4 billion per year, as compared to $9.9 billion in scenario 2
Scenario 4	▪ Impacts of scenario 4 are far less destructive than in scenario 3 because the scenario assumes only a 25% decrease in consumption of imported cereals and oilseeds ▪ Sub-Saharan Africa does not acquire the export market seen in scenario 3, but in fact loses export shares to GM adopting regions ▪ European resource allocation does not suffer inefficiencies seen in scenario 3 ▪ World welfare increases by $8.5 billion per year, as compared to $9.9 billion in scenario 2 – restrictions in Western Europe predominately account for this variance

Nielsen and Anderson extend these results in another paper with Sherman Robinson [92] to cover scenarios introducing GM cotton and GM rice. The previous assumptions of 5% productivity gains from adopting GM, sufficient demand elasticity, and appropriate movements of production factors remain.

In scenario 1, GM cotton is adopted in North America, the Southern Cone of Latin America, China, India, and the Rest of South Asia. No European import bans or changes in consumer patterns are modeled, and consumers are assumed to be indifferent between GM and non-GM products. The results are as follows[93]:

- Plant fiber production rises in all regions, although more so in North America and the Southern Cone than in China and South Asia
- The international price of cotton decreases by 4%
- African cotton production falls (under the assumption that the technology is not adopted)
- The world textile industry expands due to a fall in the price of cotton – however this change is minor due to textile trade distortions caused by North America and Western European protection
- World welfare increases by $1.7 billion, with $350 million accruing to North America
- Without trade barriers to textiles and clothing, resources would be more efficiently allocated, world welfare gains from GM cotton adoption would rise, and a larger share of these welfare gains would accrue to developing countries.

In Scenario 2, productivity enhancing rice (not health enhancing Golden rice) is adopted in North America, the Southern Cone, China, East Asian newly industrialized countries, the remainder of East Asia, India, and the remainder of South Asia, but not

[92] Nielsen, Anderson and Robinson: Estimating the Economic Effects of GMOs: The Importance of Policy Choices and Preferences
[93] Nielsen, Anderson and Robinson

Africa, Europe or Japan. Again, productivity is assumed to rise by 5% and the previous assumptions remain. The results are as follows[94]:

- World market price of rice declines by about 3%
- The domestic price of paddy rice in East and South Asia declines by 6-7%
- All adopting Asian country garner welfare gains
- Non-adopting Sub-Saharan Africa, which is a net rice exporter, faces decreased world rice prices
- World welfare increases by $6.2 billion per year, with considerable gain accruing to Western Europe as resources move out of protected rice production
- North American welfare declines trivially

The validity of each of these scenarios is limited to some degree by the relatively scant collections of accurate data. However, they do suggest something about the nature of enhancing agricultural producer capacities via GMOs. That said, the models say nothing about possible costs to the societies that produce or consume the products if something should go horribly wrong following their introduction, therefore we are not provided with an indication of expected utility in the von Neumann – Morgenstern sense discussed previously.

However what is more important to recognize here, particularly within the context of the present discussion, is the capacity for Western Europe to influence the accrual of welfare benefits to GMO adopters by banning or curtailing consumption of GMO commodities. Indeed, as the results of the first paper discussed show, worldwide welfare gains under a Western European GMO ban are merely one third of the gains under the free trade of GMOs, when the GMOs are adopted by a large percentage of producers worldwide.

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[94] Ibid

In a later set of papers, Nielsen and Andersen further extend their analysis by introducing health oriented welfare gains from GMO adoption[95]. In particular they investigate the impacts of Golden Rice adoption and the possible associated reductions in blindness caused by vitamin A deficiency. The health impacts were first estimated in a paper, by Zimmermann and Qaim,[96] which looked at disability-adjusted life years (DALY) in the Philippines following the adoption of vitamin A enhanced rice production. Nielsen and Anderson extrapolated the results for a broader sample of countries and incorporated them into the GTAP model as a conservative 3% increase in the productivity of unskilled labor (there is no productivity shock to skilled labor, as it is assumed these workers can already afford a sufficiently nutritious diet.)[97]

The role of rice in this investigation takes on a number of unique properties as compared to the cereal and oilseed crops discussed previously. First, rice is of considerable importance to developing countries, and far less critical in developed countries. Over 95% of world rice production *and consumption* occurs in developing countries, whereas the US and EU are major players in the maize and soybean markets – which are highly internationalized.[98] A second important difference, which emerges with significance in the results outlined below, is that rice is primarily consumed in the country where it is produced, with only a small share of total world rice production entering international markets.[99] That being said, rice exports are rather important for several developing countries, particularly Thailand, Vietnam and Pakistan, so a choice between

[95] See Nielsen and Anderson (2003) and Nielsen, Anderson and Jackson
[96] See Zimmermann, R. and M. Qaim. *Projecting the Benefits of Golden Rice in the Philippines,* ZEF Discussion Paper No. 51, Bonn: Center for Development Research, September 2002.
[97] Nielsen, Anderson and Jackson
[98] Nielsen and Anderson (2003)
[99] Ibid

GM and non-GM rice might be prone to international market pressures for these countries.[100]

Nielsen and Anderson's model takes a similar form to those described above. The investigation begins with a base case simulation in which 75% of US, Canadian and Argentine oilseed production is GM, while 45% of US and Canadian coarse grain production is GM and 30% of Argentina's such production is GM. GM rice production is incorporated into several scenarios, but is modeled to be production enhancing as opposed to health enhancing for the US, Canada and Argentina. These countries are assumed to adopt production enhancing GM rice because they have adopted other GM products previously. However they are not expected to show interest in health enhancing Golden Rice. Developing countries, on the other hand, are assumed to adopt health enhancing GM rice in some scenarios. Consumer aversion to GMOs in other OECD countries is accounted for as a low elasticity of substitution between GM and non-GM products. Consumers in developing Asia are assumed to have a preference for Golden Rice once it is introduced. Again, health impacts are modeled as a 3% increase in the productivity of unskilled labor.[101]

The scenarios are as follows and results are presented in table 4.2. Scenarios 1 through 3 assume Golden Rice production in adopting Asian nations[102]:

Scenario 1: US, Canada and Argentina adopt GM Coarse grains and oilseeds (not GM rice) – a farm productivity shock ensues

Scenario 2: Scenario 1 + China, south and Southeast Asian Countries adopt Golden Rice – rice demand/supply shocks, as well unskilled labor productivity shocks ensue

Scenario 3: Scenario 2 + EU, Japan and Korea impose a ban on imports of rice, coarse grains and oilseeds from countries adopting GM varieties of those crops

[100] Ibid
[101] Ibid
[102] Ibid

Scenarios 4 through 6 assume widespread adoption of non-golden GM rice to illustrate relative impacts of Golden Rice

Scenario 4: Scenario 1 + China, South and Southeast Asia, as well as the US, Canada and Argentina adopt non-golden GM rice – farm productivity shocks ensue for all adopters, but no health benefits accrue

Scenario 5: Scenario 4 + China, South and Southeast Asia also adopt GM coarse grains and oilseeds – further productivity shocks ensue

Scenario 6: Scenario 5 + EU, Japan and Korea impose a ban on imports of rice, coarse grains and oilseeds from countries adopting GM varieties of those crops

Table 4.2: Results of *GM Rice Adoption: Implications for Welfare & Poverty Alleviation*

	Results
Scenario 1	▪ World welfare increases by $2.3 billion per year - $1.3 billion of this accrues to adopters and Asia, the remainder to the EU ▪ Countries that export related competing products but do not adopt GMOs lose
Scenario 2	▪ Gains from Golden Rice adoption are nearly seven times that of the gains in scenario 1 ▪ World welfare increases by $15.2 billion per year – all but one eighth accrues to Asian countries adopting golden rice ▪ All but 15% of the gains to Asian adopting countries are the result of enhanced productivity of the unskilled labor pool – which is the model proxy for health benefits associated with the improved nutrition via Golden Rice use ▪ The GDP boost from Golden Rice makes developing Asia more affluent, expanding demand for exports and causing spill over effects to the rest of the world
Scenario 3	▪ EU, Japanese and Korean bans on the import of pertinent goods from GM adopting countries causes adopters of non-rice GM products to lose in comparison with scenarios 1 and 2 ▪ Asian adopters of Golden Rice are unaffected because they do not export rice to the GM banning countries ▪ EU, Japan and Korea suffer a welfare loss which can be weighed in comparison to their objective value of not consuming GMO
Scenario 4	▪ The addition of non-nutrition enhancing GM rice to the portfolio of GM producers in Scenario 1 plus producers in developing Asia nearly doubles the increase in global welfare over that in Scenario 1 (from $2.3 billion per year to $4.4)
Scenario 5	▪ If Scenario 4 prompted Asian producers to adopt GM grains and oilseeds, gains to world welfare rise to $4.9 billion per year
Scenario 6	▪ If the EU, Japan and Korea ban pertinent products form GM adopting countries, world welfare in fact decreases to a level below that of pre GM adoption ▪ Developing Asian countries are largely unaffected by this decrease because of the insulation of their rice markets

Once again, we see that the influence of GMO averse nations on the global markets for GM crops can be considerable. However the silver lining is the apparent insulation of rice markets in developing Asia. Indeed, the substantial benefits of Golden

Rice adoption are almost entirely unaffected by international market pressures from GMO averse nations.

Nevertheless, such a saving grace is highly context specific. The above modeling clearly illustrates the pressures that international markets impose on other GM crop markets. Thus, consider a hypothetical in which an agricultural commodity, which does not benefit from the *market insulation* enjoyed by rice, is genetically modified to improve health in developing countries in some manner different from that of Golden Rice. As long as market influencing developed countries maintained bans on this commodity from any country producing the GM crop, developing countries would in fact be forced to choose between production of the health effecting product and access to markets. Choosing the health enhancing crop could be devastating to markets and, under extreme circumstances, might even lower overall welfare in adopting countries even as health improves.

Notice that if the structure of a GM import ban is a blanket ban on any variety of the GM crop, then the adopting countries cannot sidestep the ban by producing both GM and non-GM crops, segregating those crops, and exporting only the non-GM variety. So long as GMO averse nations maintain strict traceability and commingling regulations on commodities from GM producing countries, such a ban could essentially emerge as a de facto blanket ban of the commodity if the developing countries lack the monitoring and management capacity needed to effectively segregate the GM and non-GM varieties.

Thankfully, there are no current examples of potentially health enhancing GM commodities that are exposed to significant market pressures. Rather, most of the discussion over health enhancing GM crops focuses around Golden Rice. This is in fact quite fortuitous, in that Golden Rice may, by virtue of its insulated position in international markets, enjoy the necessary leeway to develop to its full potential. Indeed, it may, in time, prove to be a critical commodity that simultaneously improves health in developing countries while illustrating the potential for the safe and welfare enhancing use of GMOs.

Of course, this is an optimistic assessment of the potential for Golden Rice, which today remains a largely uncertain technology, but under the best of circumstances, it may play a pivotal role in illustrating to the world just how valuable GM technology can be, and just how severe a price GMO aversion can place on the world's poor who have so much to gain from the potentialities of a budding and promising technology.

5 SYNTHESIS AND DISCUSSION

Let us now revisit the fundamental purpose of this investigation, which is to juxtapose the potential risks and potential benefits of GMO use so as to consider if GMO aversion overestimates the price of GMO risk and thereby imposes costs on potential GMO users in the form of foregone benefits. We have seen in section 4 that there is potential for GMO use to increase annual world welfare by billions of dollars. At the same time we have seen that aversion to GMO use can have such profound influence over international agricultural markets so as to severely reduce, and in some cases eliminate, those potential welfare gains. The question that remains is whether or not the foregone welfare benefits are proportional to the risks avoided by preventing the use of GMOs. Unfortunately, it is still quite difficult to answer this question with a large degree of certainty, but what we can do is look critically at the sources of GMO aversion and speculate as to the proportionality between the risks avoided and the benefits foregone.

5.1 Pure Risk Aversion and the Proportionality to Welfare Loss

Let us consider once again the price of risk that we defined in equation 3.2:

$$P = \frac{r_b - r_n}{\sigma_{rb}} .$$

In section 3.4, we rewrote this equation twice, once to represent the price of risk associated with conventional agricultural products and once to represent the price of risk associated with genetically modified crops. The difference between these was defined to be the incremental price of risk between conventional and GMO crops. It was then shown that scientific opinion indicates that the incremental risk between any GMO and its conventional counterpart *may* be quite low, or indeed insignificant. This is not to say that there is no risk associated with GMO use, or that the incremental risk between all GMOs and their conventional counterparts is insignificant. Rather, it suggests that some GMOs are no more risky than their conventional counterparts, but other GMOs may in fact pose greater risks. Thus, it is necessary to investigate each GMO product in isolation and determine its riskiness vis-à-vis its conventional counterpart.

Once the incremental riskiness of a GMO product is accurately assessed, it can be represented in pure monetary terms based upon the expected value of the adverse impacts that it may cause. In section 3.5 we made use of insurance pricing methods to do precisely this. We represented the monetary value of the adverse effects of GMO use as –Y. If a GMO user was required to compensate injured parties for any harm caused by GMO use, she could purchase an insurance policy that would pay an indemnity equal to –Y in the event of ill fortune. Taking the probability of an adverse outcome into consideration, we found that in a competitive insurance market the price of such an insurance policy would be equal to the probability of the adverse outcome multiplied by the indemnity to be paid. This value is the expected value of the adverse impacts that may be caused by GMO use.

If properly standardized, the expected value of this incremental risk can be directly compared to the expected value of the welfare gains identified in section 4. If the expected value of risk exceeds the expected value of benefit, then it is reasonable to forego the use of the particular GMO in question because its riskiness is greater than its potential benefit. However, if the expected value of the benefit exceeds that of the risk, then we must provide sound justification if we are to forego the use of the GMO and deprive potential users of the expected benefit.

Such justification can be hypothesized by speculating about the form of the utility function, u, employed in identifying expected utility in equation 3.1:

$$eu(a_i) = \pi_{s1} \cdot u[C(a_i, s_1)] + \ldots + \pi_S \cdot u[C(a_i, s_S)]$$

$$\text{for all } s = (s_1, \ldots, S) \text{ where all } \pi_s < 1 \text{ and } 1 = (\pi_{s1} + \ldots + \pi_S)$$

As the reader will recall, we showed in section 3.2.1 that an actor's risk premium is a function of the degree of risk aversion embodied in the utility function; the more concave the utility function, the greater a premium must be in order to convince the actor to engage in the risky behavior. Because we accepted in section 3 that all the actors pertinent to the present investigation are risk averse, there is ample justification for the presence of some degree of concavity in the utility function. But why do some countries demonstrate considerably more concave utility functions than others, and to what extent do these differentials in the willingness to accept risk impose an inordinate cost on society in the form of foregone welfare?

5.2 Risk Preference and Conventional Sources of Risk Aversion

To some degree, this differential can be explained purely as a representation of varying preferences toward risk. One might hypothesize that some countries place a greater value on the knowledge that there is no possibility for the adverse results of GMO use to emerge than others do.

Another hypothesis suggests that certain societies value human and environmental wellbeing vis-à-vis welfare increases differently than others. Perhaps richer countries that are not significantly in need of welfare increases are far less willing to take on risks than are poorer countries. This harkens to discussions along the lines of *statistical value of life*, in which it is suggested that the revealed value of human welfare in fact varies from society to society. One might extend such a hypothesis to conclude that the more developed countries (or by assumption, those countries less in need of welfare gains) would demonstrate a more concave utility function when considering the relative benefits of GMO use.

From the opposite perspective, there is reason to believe that developing countries might be more averse to the risks of GMO use than developed countries. To the extent that safe GMO development and use requires vigilant management and regulation, and to the extent that human health complications may emerge, developing countries with limited regulatory and health care capacities might be more averse to GMO use simply because they are less well prepared to manage the risks.

5.3 Political-Economy Sources of Risk Aversion

Yet another possibility is the use of *risk aversion* per se as a veil for completely different motives altogether. Because agriculture remains a highly contentious element of international trade relations, the GMO card offers both opportunities and problems to agricultural protectionist interests. To the extent that cheaper production and increased outputs lower the consumer prices of agricultural goods, some factors of agricultural production stand to lose from widespread GMO use. However the untested nature and novel characteristics of GMOs, not to mention widespread public outcry about the *dangers* that they pose, offer a means of non-tariff protection for agricultural production interests. Indeed, it is not inconceivable that an underlying motive of GMO banning policies is simply the protection of agricultural markets from cheaper commodities derived from GMO use.

5.4 Asymmetric Priorities and Preference Imposition

The sum of these, and perhaps other elements that contribute to the definition of a given country's utility function, account for the curvature differentials in the utility curves shown in figure 3.2 and, by extension, for the differentials in GMO risk premiums that are revealed by different countries. But they also suggest that there is a potential for asymmetric priorities amongst different societies. Indeed, certain wealthier, more developed countries may decide that they have little need for the welfare increasing properties of GMOs and place a greater importance on protection of human health and environmental welfare. Such an assessment increases the curvature of the utility function and thereby imposes a higher premium on GMO use. Meanwhile, lesser developed countries may choose to accept the risks of GMO use, even in the face of those risks that are enhanced by their own limited capacity to effectively manage human health and environmental risks, on account of the welfare benefits that can be garnered. In such an instance, the country will exhibit a less severely curved utility function.

For cases in which the risk preferences of one country have little or no effect on the actions of another country, this differential in risk premiums is of minimal significance. The example of Golden Rice in section 4 is just such an instance. However, in instances in which the risk preferences of one country have a strong effect on the actions of another country (such as the examples of soybeans and corn) these premium differentials have tremendous implications. As we saw from the GTAP simulations, certain markets have the power to influence returns to other markets simply by imposing their own preferences toward risk. While some of the GTAP simulations showed that the only significant losers from such actions are the countries that imposed the ban, there is evident potential for ban imposing countries to deprive other countries of considerable welfare gains if asymmetric preferences interact in certain ways and with regard to certain commodities.

6 CONCLUSIONS

This paper has reviewed two distinct sets of apparatus by which to assess the potential risks and the potential benefits of GMO use. In the absence of adequate data on the riskiness of GMOs, it remains difficult to conduct comprehensive statistical analyses by which to fully assess the empirical nature of the relationship between these. Nevertheless, by giving a theoretical treatment to the nature of risk and preferences toward risk, we have been able to hypothesize about sources of differentiation between revealed GMO risk premiums in different societies. This was juxtaposed to estimated welfare benefits that can be derived from GMO use, as well as estimates of the reduction in these welfare benefits that result from aversion to the use of, or all out bans of, GMO products in certain countries. Although it is not possible to draw definitive conclusions without ample data illustrating the risk of GMO use, the discussion herein suggests that there is considerable potential for risk aversion in one society to curtail or eliminate the benefits of GMO use for another. To the extent that different countries at different stages of development hold differing priorities with regard to incurring risk in the interest of garnering welfare improvements, the ability for one country to dictate another country's capacity to benefit from GMO use could result in the curtailment of potential welfare gains.

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