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Intellectual Property Rights and Agricultural Biotechnology: Implications and Public Policy Choices for a Developing Country

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Intellectual Property Rights and Agricultural Biotechnology: Implications and Public Policy Choices for a Developing Country" submitted by Anasuya Chattopadhyay in partial fulfillment of the requirements of the degree of Master of Arts.

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ABSTRACT

In a developing country, government policy plays an important role when agricultural biotechnology is introduced from abroad. This thesis models the strategic, sequential interaction of the host government, the foreign intellectual property rights (IPR) holder, and domestic producers, in the face of negative external effects (perceived or actual) of agricultural biotechnology, such as loss of biodiversity, loss of traditional knowledge by the farming community and concern about human health. As a policy response, the government introduces either an optimal per unit corrective tax on the genetically modified seed or an optimal per unit subsidy on the traditional seed. The relative effectiveness of the two policy instruments is influenced by some producers' ability to infringe upon the IPRs on the GM variety without detection, and by the foreign monopolist's ability to re-price the GM seeds in response to the influences of either a tax or a subsidy on the various seed varieties.

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LIST OF SYMBOLS AND ABBREVIATIONS

p_t	Price of a unit of traditional crop charged by the producer; $p_t \geq 0$.
p_t^s	Unit price of traditional seed, $p_t^s \geq 0$.
p_{gm}	Price of a unit of GM crop charged by the producer, $p_{gm} \geq 0$.
B	$p_{gm} - p_t + p_t^s$, which is the intercept of the innovator's demand curve in case (i)
γ	Return premium factor associated with the production of traditional crop for any level of exogenous producer attribute A; $\gamma \geq 0$.
ϕ	Return premium factor associated with the production of GM crop for any level of exogenous producer attribute A; $\phi \geq 0$; $\gamma > \phi \geq 0$.
δ	Probability that the producer will get caught while producing illegal GM crop; $0 \leq \delta \leq 1$.
ρ	Penalty per unit imposed by the government on the producers found to produce illegal GM crop each period.
δ_0	Probability that the producers will be audited; $0 \leq \delta_0 \leq 1$.
A	Differentiating attribute of producer characteristics;. $0 \leq A \leq 1$.
m	Constant marginal cost faced by the innovator
c	A constant; $0 \leq c \leq 1$, marginal external damages from any GM seed use in the negative externality function
α	Slope of enforcement cost function; $\alpha > 0$.
β	Intercept of enforcement cost function; $\beta > 0$.
EC	Cost associated with IPR enforcement
λ	Lagrange multiplier used for constrained optimization

Case (i): No externality, no policy measures adopted

Π_t	Producer's net returns function for a unit of traditional crop production

	under perfect enforcement
Π^{h}_{gm}	Producer's net returns function for a unit of legal GM crop production under perfect enforcement
Π^{c}_{gm}	Producer's net returns function for a unit of illegal GM crop production under perfect enforcement
p^{s}_{gm}	Unit price of legal GM seed
A_{gm}	Specific level of producers' characteristic at which producers are indifferent between producing a unit of GM or traditional crop
x^{s}_{gm}	Equilibrium quantity of GM seed demanded of the innovator by the domestic market
x^{s}_{t}	Equilibrium quantity of traditional seed used in the developing country; $x^{s}_{t} = (1 - x^{s}_{gm})$.
D^{s}_{gm}	Inverse demand faced by the innovator in the developing country
MR^{s}_{gm}	Marginal revenue function of the innovator from the sale of GM seed
W_1	Social welfare
PS_1	Producers' surplus
IR_1	Innovator's rent

Case (ii): Negative externalities occur, no policy measures adopted yet

D_2^{PE}	Negative externality associated with GM seed usage
W_2	Social welfare

Case (iii): Negative externalities occur, corrective tax imposed per unit of GM seed purchased as a policy measure

τ_0	Tax per unit of GM seed purchased
τ_0^*	Optimal rate of tax
$\tilde{\Pi}^{h}_{gm}$	Producer's net returns function for a unit of legal GM crop production

under perfect enforcement

$\tilde{p}^s_{gm}$ Unit price of GM seed inclusive of tax

$\hat{p}^s_{gm}$ Unit price of GM seed net of tax

$\tilde{A}_{gm}$ Specific level of producers' characteristic at which producers are indifferent between producing a unit of GM or traditional crop

$\tilde{x}^s_{gm}$ Equilibrium quantity of GM seed exchanged by the innovator in the domestic market

$\tilde{x}^s_t$ Equilibrium quantity of traditional seed exchanged in the developing country; $\tilde{x}^s_t = (1 - \tilde{x}^s_{gm})$.

$\tilde{D}^s_{gm}$ Inverse demand faced by the innovator in the developing country

$\tilde{MR}^s_{gm}$ Marginal revenue function of the innovator from the sale of GM seed

IR_3 Innovator's rent

W_3 Social welfare

PS_3 Producers' surplus

D_3^{PE} Negative externality associated with GM seed usage

TR_3 Tax revenue earned by the domestic government

r_3 Minimum innovator's rent

Case (iv): Negative externalities occur, corrective subsidy levied per unit of traditional seed purchased as a policy measure

$\bar{\bar{\Pi}}_t$ Producer's net returns function for a unit of traditional crop production under perfect enforcement

$\bar{\bar{\Pi}}^h_{gm}$ Producer's net returns function for a unit of legal GM crop production under perfect enforcement

η_0 Subsidy per unit of traditional seed purchased

η_0^* Optimal level of subsidy

D_t	Inverse demand faced by the traditional seed suppliers in the developing country
$\ddot{x}_t^s$	Revised quantity of traditional seed supplied in the first round
$\overline{\overline{D}}_{gm}^s$	Inverse demand faced by the innovator in the developing country
$\overline{\overline{MR}}_{gm}^s$	Marginal revenue function of the innovator from the sale of GM seed
$\overline{\overline{p}}_{gm}^s$	Unit price of legal GM seed
$\overline{\overline{x}}_{gm}^s$	Equilibrium quantity of GM seed exchanged the innovator in the domestic market
$\overline{\overline{x}}_t^s$	Equilibrium quantity of traditional seed exchanged in the developing country; $\overline{\overline{x}}_t^s = (1 - \overline{\overline{x}}_{gm}^s)$
$\overline{\overline{A}}_{gm}$	Specific level of producers' characteristic at which producers are indifferent between producing a unit of GM or traditional crop
IR_4	Innovator's rent
W_4	Social welfare
PS_4	Producers' surplus
D_4^{PE}	Negative externality associated with GM seed usage
Pa_4	Subsidy payments made by the domestic government
r_4	Minimum innovator's rent

Case (v): No externality, no policy measures adopted

$\overline{\Pi}_{gm}^h$	Producer's net returns function for a unit of legal GM crop production under imperfect enforcement
$\overline{p}_{gm}^s$	Unit price of legal GM seed
A_{gm}^c	Specific level of producers' characteristics at which producers are indifferent between producing a unit of illegal and legal GM crop

A_{gm}	Specific level of producers' characteristics at which producers are indifferent between producing a unit of GM and non-GM crop
x^{h}_{gm}	Equilibrium quantity of legal GM seed purchased
x^{c}_{gm}	Equilibrium quantity of GM seed acquired illegally
IR_5	Innovator's rent
W_5	Social welfare
PS_5	Producers' surplus
r_5	Minimum innovator's rent
F_5	Total revenue collected in the form of expected penalties from each producer who cheats

Case (vi): Negative externalities occur, no policy measures adopted yet

W_6	Social welfare
D^{PE}_{6}	Negative externality associated with GM seed usage

Case (vii): Negative externalities occur, corrective tax imposed per unit of GM seed purchased as a policy measure

$\underline{\Pi}^{h}_{gm}$	Producer's net returns function for a unit of legal GM crop production under imperfect enforcement
$\underline{p}^{s}_{gm}$	Unit price of GM seed inclusive of tax
$\breve{p}^{s}_{gm}$	Unit price of GM seed net of tax
$A^{(new)}_{gm}$	Specific level of producers' characteristics at which producers are indifferent between producing a unit of GM and non-GM crop associated with 'low' tax
$A^{c(new)}_{gm}$	Specific level of producers' characteristics at which producers are indifferent between producing a unit of illegal and legal GM crop in case of 'low' tax

f	Critical point that implicitly defines largest value of 'low' tax
A_f	Producers' attribute at the critical point f
A'	Specific level of producers' characteristics associated with the critical point 'f' in case of 'high' tax
$\underline{x}^h_{gm}$	Equilibrium quantity of legal GM seed in the post-tax scenario
$\underline{x}^c_{gm}$	Equilibrium quantity of illegally acquired GM seed in the post-tax scenario
τ_1	Tax per unit of GM seed purchased
τ_1^*	Optimal rate of tax
IR_7	Innovator's rent
W_7	Social welfare
PS_7	Producers' surplus
r_7	Minimum innovator's rent
F_7	Expected penalty
TR_7	Tax revenue
D_7^{IE}	Negative externality associated with GM seed usage

Case (viii): Negative externalities occur, corrective subsidy levied per unit of traditional seed purchased as a policy measure

Π''_t	Producer's net returns function for a unit of traditional crop production under imperfect enforcement
η_1	Subsidy per unit of traditional seed purchased
η_1^*	Optimal rate of subsidy
Π''^h_{gm}	Producer's net returns function for a unit of GM crop production under imperfect enforcement
p''^s_{gm}	Unit price of legal GM seed
A''^c_{gm}	Specific level of producers' characteristics at which producers are

	indifferent between producing a unit of illegal and legal GM crop
A''^{h}_{gm}	Specific level of producers' characteristics at which producers are indifferent between producing a unit of GM and non-GM crop
x''^{h}_{gm}	Equilibrium quantity of legal GM seed usage
x''^{c}_{gm}	Equilibrium quantity of illegal GM seed usage
x''^{s}_{t}	Equilibrium quantity of traditional seed usage; $x''^{s}_{t} = (1 - x''^{h}_{gm})$
IR_8	Innovator's rent
W_8	Social welfare
PS_8	Producers' surplus
D_8^{PE}	Negative externality associated with GM seed usage
Pa_8	Subsidy payments made by the domestic government
r_8	Minimum innovator's rent

CHAPTER ONE: INTRODUCTION

1.1 Overview of the problem

In recent years, two important developments have changed the ways through which improved crop varieties and related technology are being invented, commercialized and marketed to the farmers. The first is the development of methods and techniques in genetic manipulation, commonly referred to as biotechnology. The second is the expansion and strengthening of intellectual property rights (IPRs) that apply both to processes and products. Although both developments have been underway for more than 20 years, their importance to governments, policy makers and private corporations that are involved in the crop seed industry has increased many fold in recent years. An important issue arising out of these developments is that of the welfare implications of varying degrees of IPR enforcement in developing countries when innovations in agricultural biotechnology are introduced from the developed world. A number of economic analyses have been carried out to explore this issue. A common notion is that the developing country generally gains in terms of social welfare by enforcing IPRs less than perfectly.

Modern biotechnology uses recombinant DNA (DeoxyriboNucleic Acid) methods and cell fusion methods to produce other organisms. The term genetically modified organism (GMO) applies to any organism that has recombinant DNA, i.e., it has had DNA transferred to it from another organism (Crespi, 1988).

Intellectual property rights (IPRs) are the rights granted by the state and which exclude others from the use or benefit of the protected invention without the consent of the rights holder (Crespi, 1988). The rights to use technological innovations are regarded as intellectual property (IP), which is commercially valuable information. These IPRs are instruments used by firms to protect their innovations. The major intellectual property rights are patents, trade secrets, trade marks, copyrights, and, in the context of biotechnology, plant breeders' rights.

The expansion of IPRs into modern biotechnology is the result of increased privatization of knowledge and inventions and is under continuous debate. With a long tradition of IPRs covering inventions in various sectors, the expansion of IPRs into the biotechnology sector is relatively easier in the developed countries. With numerous ethical and environmental issues concerning biotechnology products unresolved, there is a great deal of opposition to the introduction of IPRs in agricultural biotechnology from some of the developing countries (Santaniello *et al.*, 2000).

One of the key issues in this context is the basis for the sharing of benefits related to modern biotechnology and associated IPRs. According to one school of thought, it may be unfavorable for a particular developed country to limit access to its knowledge pool of genetic resources. One reason for this is that apportioning the benefits fairly may be almost impossible or infeasible (Brush, 1994). On the other hand, according to some other researchers, the 'synergy' between IPRs and biotechnology is strong. Without protection of the property rights, the firms in the developed countries will have insufficient incentive to innovate. This suggests that some of these products would not exist without IPRs (Crespi, 1988).

In the current research, an attempt is made to evaluate the level of social welfare in the developing country in the face of some negative external effects created by the use of a genetically modified (GM) seed that is used for crop production. Specifically, this research looks at some (perceived or actual) harmful effects that might be caused by the use of GM seed and prescribes policy measures that could be adopted by the government/policy maker to counter such effects. In general, the damaging components or the negative externalities could arise from a number of sources or effects. Plantation of a transgenic variety of seeds throughout a vast area may cause genetic uniformity of plants through monoculture (Dutfield, 2000). Export of monoculture to the South causes erosion of diverse traditional knowledge of the indigenous farming community, gained through years of farming experience, which is particularly suited for the specific local conditions (Brush, 1992). Alternatively, some consumers may express their concern about negative health effects of the GM crop; such as when consumption of a GM crop may transmit allergenic components affecting human health (Royal Society, 2002).

The current research shows that in the face of such negative external effects, governmental policy, such as a corrective tax levied per unit of GM seed used or a corrective subsidy levied per unit of traditional (non-GM) seed used may improve the level of social welfare of the developing country, irrespective of the degree of IPR enforcement.

1.2 The framework of the analysis

The current research can be viewed as an addition and modification to recent economic analysis by Giannakas (2002).

In chapter 2, a brief introduction to recent developments in agricultural biotechnology and related aspects of intellectual property protection is presented. Biotechnology is defined as 'the use of information on genetically controlled traits, combined with the technical ability to alter the expression of those traits, to make or modify a product, improve plants or animals, or develop microorganisms for specific uses' (Persley and Doyle, 1999). In chapter 2, both the positive and negative effects of biotechnology are described. On the positive side, agricultural biotechnology is thought to be part of the answer to growing poverty in the developing countries of the world. By developing seeds of improved quality, such as those providing crops with higher yields, drought and pest resistance, weed or pesticide resistance, agricultural biotechnology contributes to the potential to provide world food security. On the other hand, focusing on the risks associated with agricultural biotechnology, it might seem that food security problems may be further aggravated. Research in this area reveals that agricultural biotechnology may lead to greater genetic uniformity and therefore loss in biodiversity. Agriculture or monoculture based on a uniform variety of crop may be even more vulnerable to disease and pests. Also, abundant use of a GM variety may cause erosion of indigenous farmers' knowledge. Crop genetic resources, in the form of local crop varieties have been nurtured by generations of subsistence farmers in the developing countries of the tropics.

With the advancement of industrial agriculture, these resources have become more vulnerable (Brush, 1992). In chapter 2, a concise literature review is also presented as a background for the current research and to differentiate the current research from others.

Chapter 3 uses a four stage, strategic analysis of these issues under both perfect and imperfect enforcement of IPRs by the developing country. Here it is shown how the "host" government balances the competing interests of the foreign owned innovator of the GM seed and the domestic crop producers. The analysis starts by recapitulating Giannakas' (2002) findings regarding the effects on the levels of social welfare of the developing country under perfect and imperfect enforcement of IPRs by the developing country. One interesting feature of Giannakas' (2002) analysis is that under the imperfect enforcement regime, the developing country enjoys a positive pecuniary externality in terms of lower GM seed price. In the next stage of analysis, an external damage component is added to the basic model of Giannakas (2002) to introduce the negative externality; however, no corrective policy instrument is introduced. In the following stage, a corrective tax per unit of GM seed is imposed to restrict the harmful effects of biotechnology. Finally, a corrective subsidy per unit of traditional (non-GM) seed is used as an alternative policy instrument to internalize the externality. Closed form analytical solutions for the levels of social welfare and its components, such as producers' surplus, negative externality, and tax revenue/ subsidy payments are derived and compared in all the stages.

In chapter 4, a numerical simulation is presented to illustrate the analytical results derived in chapter 3. This is done by assigning hypothetical values to the parameters of the model such that they follow the assumptions made to build the model. This is useful in that some of the analytical solutions of chapter 3 are too complex to enable ready comparison with others. This is particularly true under the assumption of imperfect enforcement, where numerical analysis provides results which are easy to compare. Using numerical analysis, it is found that the levels of welfare increase under both perfect and imperfect enforcement regimes when the policy measures are applied to counter the negative externality. In chapter 4, a comparative analysis is also carried out to study the relative effectiveness of the policy tools adopted, i.e., the tax and the subsidy. It is observed that under the perfect enforcement scenario, either the tax or the subsidy is equally efficient in raising domestic welfare. However, from a distributional perspective, different researchers or policy makers might have different opinions. As it allocates resources to the domestic producers, subsidy might be thought to be superior to the tax, which takes away resources from the producers. Alternatively, the subsidy might seem inefficient in achieving any distributional goals if it allocates resources to the land-owning class; it could instead be used to help the poor. Using numerical analysis, it is observed that under imperfect enforcement of IPRs, the optimal level of corrective tax is more efficient in reducing the level of GM seed usage and thus internalizing the externality than the optimal level of corrective subsidy. With the corrective tax, total quantity of GM seed usage falls, however, the quantity of GM seed acquired illegally increases. With the corrective subsidy, the total quantity of GM seed usage as well as the quantity of illegally acquired GM seed decreases. Consequently, social welfare increases more with tax than with subsidy.

Chapter 5 presents the summary and conclusions of the analysis carried out in chapters 3 and 4. One of the important contributions of this chapter is the presentation of directions and scope for future research based on the current research. The current research could be extended and improved by carrying out an empirical analysis of country specific problems and/or by using a sensitivity analysis to examine the robustness of the current model when some assumptions are altered.

CHAPTER TWO: LITERATURE REVIEW

Today, almost a billion people worldwide live in abject poverty and undernourishment (Persley and Doyle, 1999). This phenomenon is prominent in the developing countries, where most people depend on the primary sector of the economy for living. Natural disasters such as drought, famine, floods and storms often cause substantial loss of crops in the tropical region leading to financial uncertainties for the farmers and their families. Moreover, epidemics of pests and weeds often ruin a large quantity of crops. Livestock suffer from parasitic diseases, some of which also affect humans. In order to increase agricultural production in these regions, farmers can resort to extensive and/ or intensive adjustments. Under intensive adjustments, farmers take measures so as to increase the output but keep the total area under cultivation constant. Extensive adjustments include bringing more land under cultivation. In some cases, this leads to destruction of forests and wildlife, which has a detrimental effect on the earth's environment.

Given these many challenges, biotechnology has played a significant role in creating new wealth in a few rich countries of the North. Given suitable conditions, the adoption of biotechnology can help improve the health, well-being and lifestyle of mankind. The issue at hand is whether biotechnology can be adopted and used in the developing countries to address problems typical to these countries, such as poverty. Although modern biotechnology may not be a panacea for all these problems, it can be critical component of the solution if it is guided by appropriate policies (Flavell, 1999).

The next section describes briefly the revolution in genetic engineering within molecular biology and the introduction of intellectual property rights in the agricultural sector. Section 2.2 discusses the benefits and risks of this new technology, in the context of a developing country. Section 2.3 addresses the negative external effects of biotechnology such as loss in biodiversity, loss in traditional knowledge by the farming community and threats to human health. Section 2.4 analyzes some of the existing models in the economics literature that deal with this issue. Finally, section 2.5 summarizes and concludes the chapter.

2.1 Genetic modification of agricultural crops and application of intellectual property rights in biotechnology

From ancient times, human societies have carried out modifications of natural species using means such as seed selection and controlled breeding. This practice reached spectacular heights with the breakthroughs in basic genetic science in the early 20th century which led to the emergence of hybrid seed varieties for important food crops, and by the mid-century, to high-yielding variety of seed through the 'Green Revolution.' In 1953, molecular biology was revolutionized with the discovery of the double helical structure of DNA (DeoxyriboNucleic Acid) molecules that are the critical constituents of genes. In 1973, scientists began engineering the recombination of DNA by moving specific genes carrying desired traits from a source organism into the DNA of a living target organism. This genetic transformation technique has been called genetic engineering, and is now more commonly known as genetic modification (GM). In this analysis, the term genetically modified organism (GMO) is used to mean any organism that has recombinant DNA, implying it has had DNA transferred to it from another organism (Gaisford, *et al.*, 2001).

The modern commercial GM crop revolution began only in 1995-96 (Paarlberg, 2000). A number of new GM corn, cotton and soybean varieties were engineered to resist pests and viruses. These varieties received approval from regulators and were released for commercial use in a number of countries, led by the United States. Farmers were quickly attracted to these new varieties as these required less management and less pesticide or herbicide usage. By 1999, Argentina, Canada and the United States accounted for 99 percent of total GM crop production in the world. The reason for this confinement of GM crop acreage was that the private organizations developing GM varieties carried out research and development solely on a profit motive. Specifically, they initially designed the new varieties for use by richer farmers in the developed world with the purchasing power to support the new products. Subsistence farmers in the developing countries were not targeted as consumers of these GM inputs (Paarlberg, 2000).

In recent years, other important developments, namely the expansion and strengthening of intellectual property rights (IPRs) that apply to processes and products, have changed the way in which improved crop varieties and related technology are being innovated and commercialized. Until recently, the research and development of new crop varieties were largely undertaken in the public sector with limited incentives provided by the traditional IPR systems. A new IPR, the 'Breeders' Right', was established in the 1950s and 1960s, which stimulated more private sector firms to carry out research in this emerging sector. Later, the expansion of scope of the Patent Right and the emergence of the Farmers' Right, which originated in the Convention on Biological Diversity (CBD) have provided some form of 'right to exclude' others from using genetic resources. The expansion of IPRs into biotechnology is part of the process of increased privatization of basic knowledge (Santaniello *et al.*, 2000).

Expansion of IPRs to protect modern biotechnology products is subject to tremendous dispute and contention. Opposition to genetically modified organisms (GMOs) is strong in many countries with bio-safety questions unsettled and ethical issues debated. While some governments have taken a permissive regulatory attitude toward new GM crop technologies, other governments have taken a more cautious view. The United States took a more permissive approach with no new labeling and segregation restrictions required on food produced using GM seeds. The governments of Canada and Argentina followed a similar path. However, the European Union adopted a rather conservative attitude in response to the issues of heath and environment. Motivated in part by the experience of the 'mad cow disease' crisis that occurred in Europe in 1996, the governments imposed labeling requirements on GM foods in 1997 and blocked any new registration of GM varieties in 1998 (Paarlberg, 2000).

Genetically modified crops were first marketed in 1996 (Moschini, 2001). By 1999, GM crops were cultivated on about 100 million acres of the total agricultural land world wide. The major crops produced using the new technology were soybeans, corn, cotton and canola. The element of the new technology for soybeans and canola was herbicide resistance. The 'Roundup Ready' varieties of these crops are resistant to glyphosate, an effective post-emergence herbicide. For cotton and corn, the transgenic qualities are herbicide resistance as well as insect resistance. During the period 1996 to 2000, commercial production of GM crops was carried out in twelve countries; however, 99 percent of this production was in the United States, Canada and Argentina. In 1999, soybeans accounted for over 50 percent of the GM crops produced, corn accounted for about 25 percent and cotton and canola were about 10 percent each (Moschini, 2001; Gaisford *et al.*, 2001)

2.2 Benefits and risks of biotechnology

The application of biotechnology in sectors such as agriculture has produced a growing number of GMOs and products from them. The potential ecological, human health and socio-economic effects of such applications have turned out to be the center of extensive debate at national and international levels.

Benefits arising due to the introduction of agricultural biotechnology are accrued by the farmers and the suppliers of complementary inputs such as the herbicide "Roundup." In particular, pest resistance and weed control characteristics of GM inputs help increase crop yields. This in turn transfers higher surplus to the producers. A related benefit is reduction in soil erosion – usage of pest resistant inputs implies less application of chemicals to the soil enabling the soil to retain a higher level of moisture. Some indirect benefits accrue to the consumers of such products as well. Increase of yield implies reduced cost (per unit) of production, which sometimes leads to a fall in price of the output. This helps the consumers to enjoy higher consumers' surplus.

Developing countries of the world may benefit from genetically modified food, crops and other GM organisms to a large extent. GM techniques for creating virus-resistant, drought-tolerant and nutrient-enhanced crops can significantly reduce malnutrition and other related problems. The risk of crop losses due to pests and weeds are often higher in developing countries and the conventional tools (for example, chemical and biological pesticides) to do away with these problems are either unavailable or unaffordable in many cases. The need to produce more food is particularly imperative in developing countries, home of nearly the entire world's undernourished today as well as of 90 percent of the population growth (Tai, 2002).

Whether the new technology promises to be the key technological innovation in the struggle for food security depends on how the associated risk factors are perceived, separated and dealt with (Leisinger, 1999). Many researchers are of the opinion that intellectual property rights of biotechnology products lead to more extensive use of GM variety which in turn encourages monoculture and thereby causes erosion of biodiversity. Assigning IPRs on biotechnology products makes research and development focus on GM varieties as these are relatively profitable, thus leading to environmental homogeneity. Crops in such cases may become more vulnerable to diseases and pests (Dutfield, 2000).

The developing countries of the world are rich in traditional knowledge of the farming community. Farmers, through generations of farming practices have acquired enormous knowledge about crop varieties, soil type and related aspects. Monoculture implies that these farmers would farm only a single crop variety over their entire available land. As it is very likely that this single (GM) crop variety is not indigenous to the area, the farmers would lose the usefulness of their traditional knowledge that relates to diverse varieties. Thus monoculture might lead to erosion of traditional farming knowledge and consequently to loss of numerous rare crop varieties.

Another important risk issue is associated with people's concern regarding potential detrimental effects on personal health from consuming products of biotechnology. A few scientists believe that the process of genetic modification disrupts the host gene function and results in unpredictable outcomes. As an example, there is concern about the possibility of transmitting allergenic components from one GM crop to another causing unpredictable allergic reaction in humans. Therefore, consuming GM crops may lead to unwanted health effects (Gaisford *et al.*, 2001).

2.3 Negative external effects of biotechnology

In the current analysis, the potential negative external effects of GM technology are addressed from the perspective of a developing economy. The objective of the analysis is to design public policies to take into account these externalities. In this section the risk issues of agricultural biotechnology are discussed in more detail.

2.3.1 Loss of biodiversity

The key question posed by the researchers in this context is whether the application of biotechnology and the expansion of IPRs to incorporate biotechnology are leading to genetic uniformity. As has been suggested by Dutfield (2000), protection of GM technology products through IPRs creates incentive for developing only genetically modified varieties of seeds since they have high demand. The organizations tend to carry out research and development in those sectors that may yield huge profits in the short run. Research is potentially centered on high-yielding variety seeds, for example. This in turn leads to the danger of genetic uniformity by inducing farmers to cultivate a single variety of crop as widely as possible. As described by Shand (1998), in the Philippines, thousands of rice varieties used to be cultivated. By the mid-1980s, two Green Revolution varieties occupied 98 percent of the entire rice growing area of the country. Nearly 1.4 percent of the earth's surface (constituting about one-third of the biodiversity) is threatened today with complete ecological breakdown in the event of natural disaster or further human encroachment (World Bank, 2002). Shand (1998) points out that the erosion of crop diversity is detrimental to world food security – the long run improvement of agriculture depends largely on the maintenance of biodiversity.

2.3.2 Loss of traditional knowledge

As a result of the introduction of biotechnology in agriculture, agricultural output in the United States during the 20th century, for example, increased about five fold. The striking feature is that, input usage has remained more or less the same, resulting in a tremendous productivity gain. Examining the trend in production, it is observed that the yields of corn and soybeans in the United States have increased enormously (Moschini, 2001). There are a few negative effects of this impressive success of the new technology – namely, erosion of traditional knowledge of the indigenous farming community. This remarkable success of industrial agriculture has nearly depleted the farming community's internal resources – their traditional knowledge. Shand (1998) pointed out that the spread of industrial agriculture caused displacement of more diverse, traditional agricultural systems to some extent. Farmers are tempted to use the transgenic version of a high-yielding variety of seeds in vast areas, instead of the diverse varieties created through years of farming practice. This again leads to the issue of monoculture and possible environmental damage. Researchers of transgenic traits are becoming more and more worried about the availability of the ultimate source of crop genetic resources, the traditional farming system of the tropical regions (Brush, 1992).

2.3.3 Threat to human health

People's negative attitude towards the consumption of GM food is an important issue. Introduction of a new gene into a plant or a change in the expression of the existing gene may cause that plant to become allergenic. It may induce allergic responses in individuals who are sensitive to that allergen or it may make individuals newly allergic to that allergen. Another concern associated with GM food is that a gene introduced into the plant may become incorporated into the consumer's genetic make-up. However, recent reports claim that the risk of allergy from the consumption of a GM variety has not yet been proven to be greater than that from traditional crop (Royal Society, 2002).

Sections 2.2 and 2.3 have described the pros and cons of agricultural biotechnology and the resultant use of genetically modified seeds for crop production. On the one hand, agricultural biotechnology can provide food security to the poor of the developing countries to some extent, through the development of high-yielding, or drought, or pest-resistant seed varieties. On the other hand, extensive use of GM varieties may lead to harmful effects such as loss of agricultural biodiversity, loss of folk knowledge of the farmers, or the possibilities of negative health effects. A separate literature and research program explores those issues (Shand, 1998). It is sufficient for this research to point toward the fact that there is a perception of harm for at least some crops produced using GM seeds.

2.4 Existing models in the economics literature

In the modern knowledge-based economy, the economic prosperity of firms and nations depends, to large extent, on their ability to innovate and exploit new technology. Technological innovations are regarded as intellectual property (IP), which is commercially valuable information. Intellectual property rights (IPRs) are instruments used by firms to protect their innovations. The major intellectual property rights are patents, trade secrets, trade marks, copyrights, and, in the context of biotechnology, plant breeders' rights (Rafiquzzaman and Ghosh, 2001).

On a global scale, the international law of IPRs consists of multilateral treaties, regional treaties and bilateral agreements. The multilateral treaties are mainly administered by the World Intellectual Property Organization (WIPO). Important examples of these types of treaties include the Patent Cooperation Treaty and the Paris Convention for the Protection of Intellectual Property. An example of a regional treaty is the European Patent Convention.

In the context of biotechnology, the most important of the IPR treaties are the Trade-Related Aspects of Intellectual Property Rights (TRIPS) and the Convention of the International Union for the Protection of New Varieties of Plants (The UPOV Convention). The former, which is administered by the World Trade Organisation (WTO), tries to enforce universal minimum standards for the protection of intellectual property. The latter, administered by the International Union for the Protection of New Varieties of Plants (UPOV) is important as it deals specifically with plant varieties.

In the developed countries, a systematic enforcement of IPRs began only during the last 40 years. Importance of IPRs has grown many-fold in the developed world due to the rapid rise of various knowledge-based economies – namely information technology (IT) and biotechnology. On the other hand, in the developing world, there has been less motivation to modernize IPR systems. This scenario is expected to change with the enforcement of TRIPS under which all nations need to enforce minimum levels of IPR protection (Girsberger, 1999; Crespi, 1988; Dutfield, 2000). One motivation for the adoption of IPRs in any developing country is that the innovation may not be sold to that country unless the IPR is enforced.

There exists a tradeoff between the incentives for innovation and the extent of monopoly power. In particular, when a firm receives protection for its innovation in the form of IPRs, it enjoys considerable monopoly power during the period for which the IPRs are valid. Lack of protection for the innovator's rights might lead to insufficient incentive for research and development. On the other hand, monopoly power may lead to inefficiency in the form of static deadweight loss in social welfare. There has been significant economics research on this issue. All these works attempt to develop a structure for an optimal IPR regime (Gilbert and Shapiro, 1990; Green and Scotchmer, 1995).

There is a growing literature that explores theoretically and empirically the welfare impacts of alternative IPR regimes. IPRs may be enforced completely, so that every user of the new technology product needs to pay a license fee to the innovator. In other cases, IPRs may be enforced less than completely, in which case some users may have access to the new technology product illegally. Deardorff (1992) examines the issue of extending patent protection from the country where an invention takes place, i.e., the developed country or the North, to a country which is a net consumer of the new technology product, i.e., the developing country or the South, using a simple model of invention. The analysis reveals that with extension of effective patent protection, the North gains in terms of social welfare whereas the South loses. Moreover, the model shows that the loss in welfare experienced by the South more than offsets the gain to the North and therefore, the aggregate world welfare falls. In another model of North–South technology transfer, Taylor (1993) shows how a reduction in patent protection by South, rather than lowering the incentives to conduct research and development (R&D) on the part of the North, raises the North's incentives to employ other barriers to imitation.

Vishwasrao (1994) incorporates asymmetric information in a partial equilibrium, game theoretic setting and explores the issue of technology transfer from the North to the South and the related welfare implications. Her paper shows that the gains to the South from the lack of IPRs protection may be offset by strategic behavior by the firm in the North that transfers technology through subsidiary or monopoly production. Zigic (1998) using an applied duopoly model with technology spillovers, considers the issue of IPR protection in North–South relations. The major insights provided by this paper are that the common assumption the South is generally better off in terms of social welfare by implementing a relaxed IPRs regime, is not robust. In other words, in the spillover framework of Zigic (1998), IPRs infringement by the South might not always have positive effects on its social welfare.

In most of the works described above, the focus is generally on how the provisions of intellectual property rights in both the North and the South influence the incentive to carry out research and development in the North and the transfer of technological innovation between the two countries. These analyses point more toward potential gains from improving North–South trade relations through intellectual property protections.

In a recent paper, Perrin (1999) describes how the South might benefit from stronger IPRs because of a tilt of inventive activity toward more South-appropriate technology. Other beneficial effects of stricter IPR protection in the South include a quality effect, a technology transfer effect and a learning effect. The quality effect arises due to the fact that distributors of pirated/ illegal products do not have the incentive to provide warranties or similar quality assurances. The successful introduction and maintenance of new technology in the South may require human or investment capital which can be provided only by the innovators of the North – the technology transfer effect. In the absence of IPRs in the South, the rights holder of the North may not have sufficient incentive to provide these investments. Thus according to Perrin (1999), a strict IPRs regime in the South leads to a successful technology transfer from the North to the South. When a new technology is introduced to the South, it induces an advancement of technical know-how among people in the South. This is referred to as the learning effect by Perrin (1999), which increases the South's capability to create further innovations.

In a more recently published economic analysis by Giannakas (2002), the issue of IPRs piracy or 'cheating' has been explored from a slightly different angle. The analysis examines intellectual property rights enforced by a developing country when an innovator in the developed country introduces a new GM variety of seed. This paper shows how the "host" government balances the competing interests of the foreign rights holder, i.e., the innovator and the domestic crop producers by explicitly choosing to enforce the IPRs imperfectly. One of the noteworthy findings of Giannakas' (2002) analysis is the recognition of a positive pecuniary externality in the process of imperfect enforcement of IPRs. In particular, as the government implements less than complete protection of the innovator's rights, a new group of domestic producers emerges whose members acquire the new technology product (GM seed) by illegal means, without paying the price of the seed. In the presence of this phenomenon, the foreign innovator needs to lower the price of legal GM seed to maximize profits. Giannakas (2002) describes this as a positive externality enjoyed by the domestic producers who purchase the GM seed; the positive externality is absent under perfect enforcement of IPRs.

In the next chapter, following Giannakas (2002), it is assumed that the developing country's government decides to allow the importation of a GM seed variety from a developed country innovator, who becomes a monopolist in the GM seed market. The problem here is unique as the monopolist is foreign and thus the rent earned by it is repatriated to the foreign country. Thus the 'first best' outcome is ruled out because of the inefficiency arising from the existence of the monopoly power and the 'second best' outcome is also ruled out as the rent is not redistributed among the agents of the domestic country, rather, it is lost altogether because of its repatriation by the foreign country. Thus, the model introduces two forms of loss in the level of social welfare in the developing country that accompany any gains from the new variety itself.

Following Giannakas (2002), the domestic producers considered here are assumed to possess heterogeneous characteristics. Producers may be thought to differ in terms of their farming environment, such as its climate and soil quality. In this case, it is assumed that producers with low quality of soil for example, tend to gain the most from adoption of the GM variety, whereas, those with improved conditions use the traditional variety.

The model introduced in chapter 3, extends the analysis of Giannakas (2002) to include a new GM variety of seed that may also bring disadvantages to the adopting country. For example, there may be risks related to the loss of environmental biodiversity, loss of traditional knowledge by the indigenous farmers, and negative effects on human health described in section 2.3 above. This model shows that in the presence of such negative externalities, the positive effect introduced by Giannakas (2002) may be offset partially or completely. The current model proposes government policy measures such as a corrective tax or a corrective subsidy that may internalize the negative externality to some extent. Closed form analytical solutions show that either the tax or the subsidy raises the social welfare of the developing country, however, because of the presence of the foreign monopolist (innovator), the 'first best' outcome cannot be attained by a single corrective instrument. The model is analyzed in chapters 3 and 4.

2.5 Summary and conclusions

This chapter has provided a brief introduction to the history of genetic modifications of agricultural crops and has reviewed some of the debate over the application of intellectual property rights to the agricultural sector. In recent years, many researchers have proposed that agricultural biotechnology should be thought of as an answer to the problems faced by the developing countries of the world, such as poverty and malnutrition. For example, through the development of pest resistant seed varieties, the quality and yield of crops can be improved significantly. On the other hand, research in this sector reveals that use of a GM variety may be detrimental. Monoculture with a single GM crop in a vast area might lead to genetic uniformity of crops, causing loss of agricultural biodiversity and other related problems. The current research aims at structuring some public policies relevant to the developing countries of the world. As is shown using game theory and numerical simulations in chapters 3 and 4, adoption of a policy tool such as a tax or a subsidy improves the level of social welfare of the developing countries.

CHAPTER THREE: REVISED MODEL OF IPR ENFORCEMENT IN BIOTECHNOLOGY

In this chapter, an economic model of IPR enforcement is proposed that takes into account both the beneficial and the potentially adverse effects of biotechnology on the economy of the country that adopts the new technology. In particular, this model incorporates any general kind of negative external effects arising due to the cultivation of genetically modified (GM) crops, such as damages caused to human health and the environment. The current model is an extension of the work described in Giannakas (2002).

There are three sets of agents in the model, namely, the heterogeneous producers of a crop in the developing country, an innovator who produces a genetically modified variety of seed in the developed country for sale in the developing country and the social planner/government in the developing country. Producers are assumed to face a competitive market and they aim at maximizing their payoffs or net returns derived from crop production (using either genetically modified or traditional varieties). The foreign innovator is a monopolist vendor of GM seed in the developing country. Therefore, the innovator determines the price of the GM seed by maximizing profits, and producers take the price of GM seed as given. The developing country in the model is assumed to be a small open economy. Therefore, the prices of the traditional seed and of all crops are determined on the world market and are taken by the producers. Finally, the government in the developing country faces the problem of maximizing social welfare. By having already implemented intellectual property rights, the government balances the competing interests of the domestic producers and the foreign innovators, and considers the use of a new policy instrument to address externalities.

In the model, the developing country government has already decided to allow the importation of a new GM variety of seeds from the innovator in the developed country. The innovator is a monopolist in the GM seed market. Therefore, importing its product implies the profits earned by the monopolist are repatriated to the foreign country. Thus, the domestic government incurs a related loss in the level of social welfare. Moreover, the new variety may introduce both positive and negative externalities in addition to the productivity gains to be experienced by domestic producers. Thus, the "host" government may play a strategic role in enforcing IPRs and in regulating the use of a new technology. The current analysis models the strategic, sequential interaction of the domestic government, the foreign innovator, and domestic producers, all operating in a small open economy.

In the next section, the case of perfect enforcement of IPRs on the part of the developing country economy is presented. Later in the same section, taxation is introduced as a government policy measure to counter the negative externalities and the tax's implications under perfect enforcement regime are discussed. This is followed in section 3.2 by the case of imperfect enforcement of IPRs in the developing country and taxation as a policy instrument under an imperfect enforcement regime. Sections 3.3 and 3.4 analyze subsidization as a policy instrument to counter the negative externalities emanating from agricultural biotechnology under perfect and imperfect enforcement of IPRs scenarios, respectively. Section 3.5 summarizes and concludes the chapter.

3.1 Perfect enforcement of intellectual property rights in the developing country

The problem is illustrated using an extensive form representation of a static game shown in Figure 3.1. In this game, government in the developing country enforces the IPRs perfectly, implying that the domestic producers act fully in accordance with the provisions of the IPRs. In the first stage of the game, there is a decision node for the government where it decides on either a tax (at rate τ_0) or a subsidy (at rate η_0) as a policy instrument to counter negative externalities from the GM variety. Next, a decision node for the innovator is reached where it decides on the price of the GM seed to be charged in the developing country market. In the third stage of the game, domestic producers decide the type of crop (GM or traditional) to produce. The game is solved using backward induction.

The game described in Figure 3.1 is a non-cooperative, static game of complete and perfect information, implying that the moves occur in sequence, all previous moves are observed before the next move is chosen and the players' payoffs from each feasible combination are common knowledge. It is a single period game signifying the short run nature of the analysis and ruling out entry and exit decisions on the part of the agents. Moreover, it is assumed that the producers face a standard convex, monotonic production technology.

The solution of the game is a backward induction outcome which does not involve non-credible threats. In ruling out the possibility of non-credible threats, consider the concept of a subgame perfect Nash equilibrium (SPNE). A subgame is a smaller game within the complete game. Beginning at a particular point in the original game, a subgame includes all subsequent choices that must be made if the agents actually reached that point in the game. A strategy profile is a SPNE if the strategies are Nash equilibrium in every subgame. There may be multiple Nash equilibria in a game, but only the SPNE is the one associated with the backward induction outcome (Gibbons, 1992; Church and Ware, 2000; Varian, 1992).

Following the method of backward induction, the analysis begins at the last stage of the game, i.e., the domestic producer's move. Here, according to Giannakas (2002, 483), 'producers differ in terms of age, education, experience, management skills, technology adopted, size and location of the farm, degree of specialization, etc.' Let A denote the quantifiable attribute that differentiates producers, distributed uniformly between zero and 1 ($0 \leq A \leq 1$). A producer determines whether to produce a non-GM crop, i.e., the traditional variety, or a GM crop, depending on his or her 'A' value. The differentiating attribute, A, is the independent variable that defines or influences the net returns available from alternate crop varieties. In the current analysis, this differentiating attribute can be thought of as any one of, or some composite of, various characteristics of the producers, such as the degree of resistance of each producer's crop (or cropping location) to (partial) yield losses due to frost, drought, soil salinity or pests.

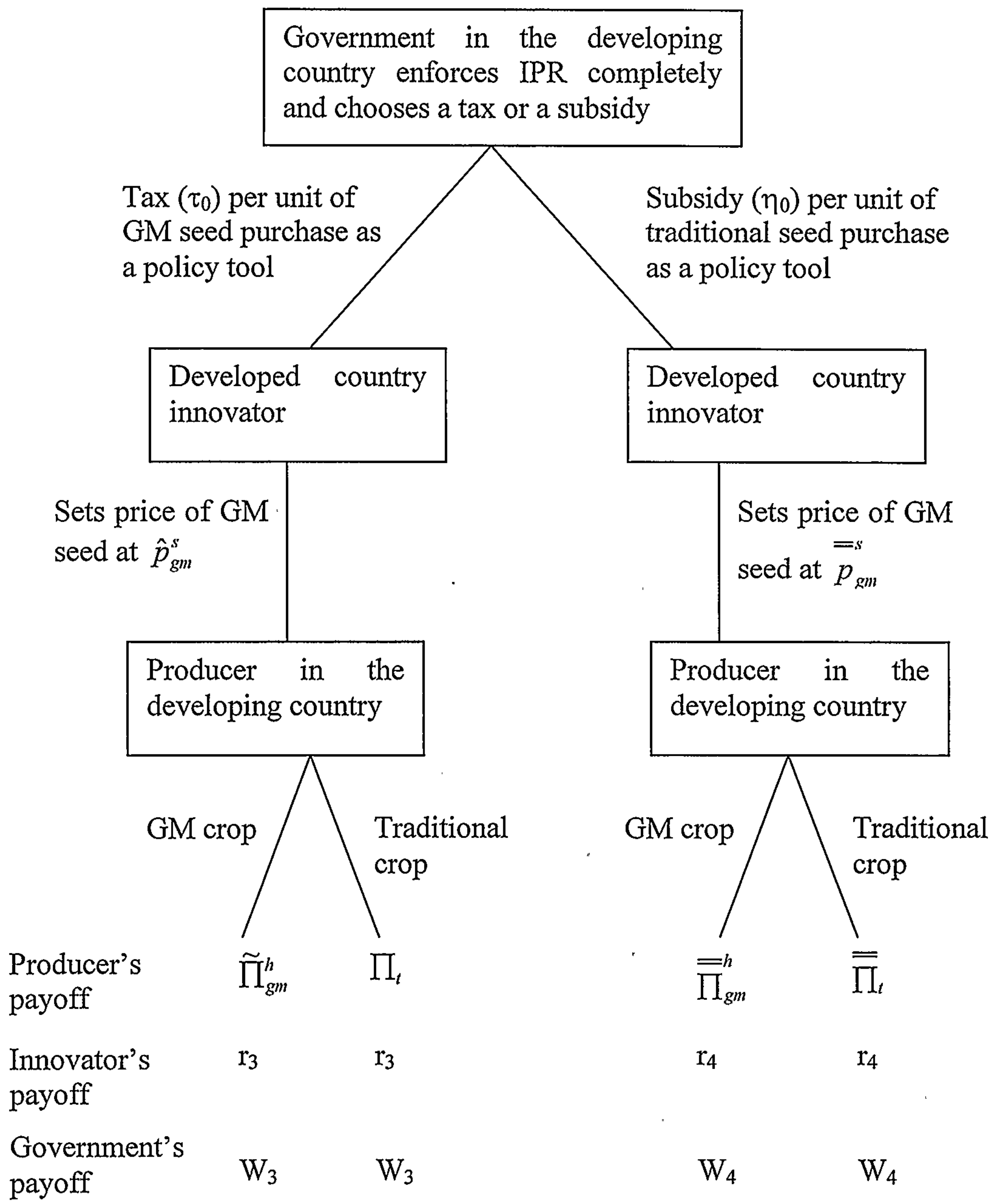

Figure 3.1: Game tree illustrating perfect enforcement of IPRs

Note that the attribute A is defined such that a lower value of A implies the producers find it more profitable to use GM seeds for crop production while a higher value of A suggests the producers will favour the use of traditional seeds.

Assuming Π_t to be the net returns earned by each producer while producing a unit of traditional crop, p_t, to be the farm price of the traditional crop (net of all production costs except for seed) and p_t^s to be the price of traditional seed, equation (3.1) describes net returns accruing to the producer for a unit of traditional crop production

$$\Pi_t = p_t - p_t^s + \gamma A \qquad (3.1).$$

The variable Π_{gm}^h denotes the net returns of each producer associated with the production of a unit of GM crop, where p_{gm} is the farm price of GM output (net of all production costs except for seed) and p_{gm}^s is the price of the GM seed. Equation (3.2) gives the net returns for a unit of GM crop produced using GM seed acquired legally

$$\Pi_{gm}^h = p_{gm} - p_{gm}^s + \phi A \qquad (3.2).$$

Producers' resistance to production risks and yield losses, as reflected in the production attributes, A, affects the crop returns through the parameters $\gamma > \phi > 0$.

It may be possible for producers to reproduce the GM seed by reverse engineering or by saving some of last season's seeds. If so, the producers will be able to produce GM output and enjoy the higher profits associated with it, without paying the full price of GM seed p_{gm}^s. This phenomenon is treated as a violation of the innovator's IPR and is described in the imperfect enforcement of IPRs scenario. To avoid such case, under the perfect enforcement regime, it is assumed that the GM seed used by the producers in the first round of cultivation of GM crop is modified to possess a so-called 'terminator gene.' Under such a circumstance, producers cannot collect viable seeds from last year's crop and this automatically leads to perfect enforcement of the innovator's property rights.

Perfect enforcement of the IPRs is examined in a series of four cases summarized in Table 3.1 below.

Enforcement Regime	Analytical cases
Perfect Enforcement of IPRs	Case (i): No externality, no policy measures adopted
	Case (ii): Negative externalities occur, no policy measures adopted yet
	Case (iii): Negative externalities occur, corrective tax imposed per unit of GM seed purchased as a policy measure
	Case (iv): Negative externalities occur, corrective subsidy levied per unit of traditional seed purchased as a policy measure

Table 3.1: Description of various cases for analyzing perfect enforcement of the IPRs

In the first case, there are no negative externalities and as a result, no policy tools are required. This is a replication of the benchmark case in Giannakas (2002) with the variation being the assumption about the one-to-one correspondence between the levels of input and output. In particular, Ginnakas (2002) assumed fixed proportions between seed and farm output. This assumption is not considered in the present analysis. Case (ii) is the intermediate case in which negative external effects of biotechnology are recognized, but the government does not adopt any policy instruments as a corrective action. This will help understand the specific effects of externality on social welfare and the potential gain by bringing in policy instruments. Finally, in case (iii) and case (iv), in response to the externalities, government as a social planner introduces alternative policy tools. Cases (i) through (iii) are discussed below in sub-sections 3.1.1 to 3.1.3 and case (iv) is described separately in section 3.3.

3.1.1 Case (i): No externality, no policy measures adopted

Here, a brief discussion is presented on the results derived in the benchmark case in Giannakas (2002). The net returns functions of the producers are shown using Figure 3.2. The vertical axis measures the net returns earned per time period by the producer and the horizontal axis measures the differentiating attribute A. The curves Π_t and Π^h_{gm} represent equations (3.1) and (3.2) respectively. From the equations, it is observed that Π_t has a slope of γ and an intercept of $p_t - p^s_t$; Π^h_{gm} has a slope equal to ϕ and an intercept of $p_{gm} - p^s_{gm}$. By assumption $\gamma > \phi$ and the producer's attribute A is exogenous. As in Giannakas (2002), there is a necessary condition to ensure that producers face a meaningful choice of the two available crop varieties that results in some of each being chosen. The pricing and productivity characteristics of the two crops must be such that:

$$(\gamma - \phi) > [(p_{gm} - p^s_{gm}) - (p_t - p^s_t)] > 0 \qquad (3.3).$$

This condition states that, in order for neither variety to dominate the entire seed market, the GM crop must be profitable for producers with low A values, but that the advantage of the GM crop must dissipate for those producers whose A values are relatively higher.

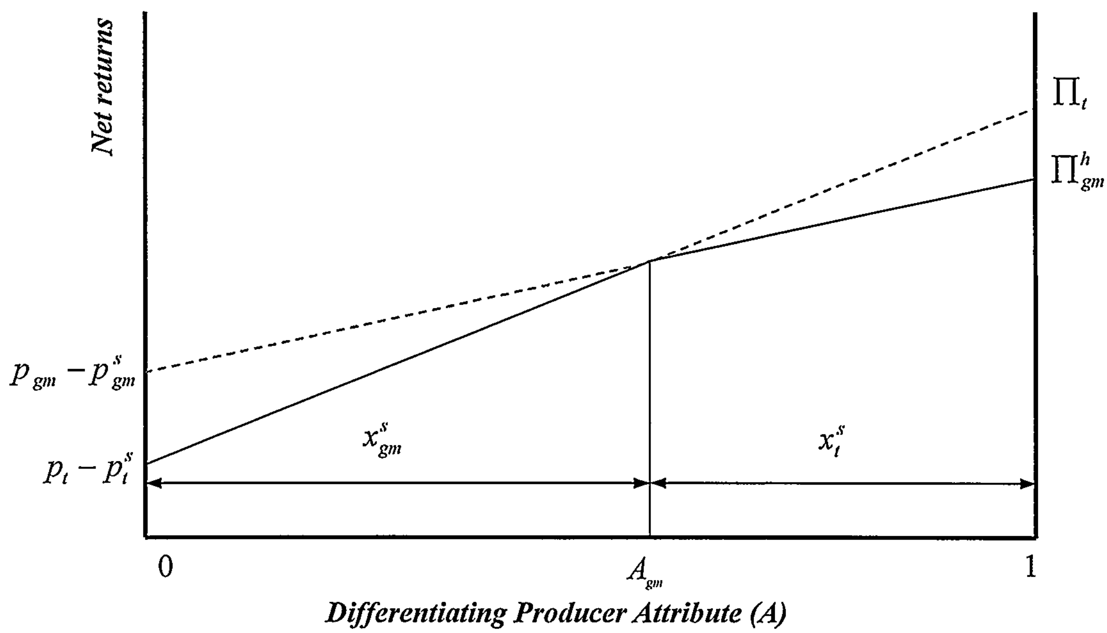

Figure 3.2: Production decision and producers' net returns under perfect enforcement of IPRs (modified after Giannakas, 2002)

According to Figure 3.2, producers located to the left of A_{gm} derive higher net returns from the production of the GM crop, since, in this region, Π^h_{gm} (dotted portion) lies above Π_t. On the other hand, producers located to the right of A_{gm} find it more profitable to produce the traditional crop, as Π_t (dotted portion) lies above Π^h_{gm}. The producer with characteristic A_{gm} is indifferent between producing a unit of the GM or traditional crop and this boundary level of A is given by

$$A_{gm} = \frac{(p_{gm} - p^s_{gm}) - (p_t - p^s_t)}{\gamma - \phi} \qquad (3.4),$$

which is derived by equating Π^h_{gm} to Π_t. By observation of (3.4), all else being equal, more producers use GM seed the lower is the GM seed price or the higher is the traditional seed price. Similar to Giannakas (2002), it is assumed that since the producers are distributed uniformly between 0 and 1, normalizing the mass of producers at unity, A_{gm} also gives the level of use of GM seed, x^s_{gm} as

$$x^s_{gm} = \frac{(p_{gm} - p^s_{gm}) - (p_t - p^s_t)}{\gamma - \phi} \qquad (3.5).$$

However, another assumption made by Giannakas (2002) about one-to-one correspondence between GM seed and GM output is not considered in this analysis. For example, if the GM crop raises yields for producers with a low A value, the fraction of producers using each type of seed will not necessarily match the fraction of total output coming from each group.

In the second stage of the game tree, the innovator decides on the price of GM seed, p^s_{gm}. The innovator's problem can be formally stated as:

$$\max_{p^s_{gm}} \pi = (p^s_{gm} - m)x^s_{gm}.$$

The short-run profit of the innovator, denoted by π, consists of the price of the GM seed in the developing country market net of the constant marginal cost m, multiplied by the total quantity of GM seed sold to the producers. Solving this problem (derivations are provided in Section 3.1(A) of Appendix A), the equilibrium price is

$$p^s_{gm} = \frac{p_{gm} - p_t + p^s_t + m}{2} \qquad (3.6).$$

Substituting (3.6) into (3.5), the equilibrium quantity of GM seed usage becomes

$$x^{s}_{gm} = \frac{p_{gm} - p_t + p_t^s - m}{2(\gamma - \phi)} \qquad (3.7).$$

Figure 3.3 shows the inverse demand function faced by the innovator and the determination of the equilibrium price and quantity of GM seed. The inverse demand function, derived by substituting the value of m from equation (3.7) into equation (3.6), is given by $p^s_{gm} = p_{gm} - p_t + p^s_t - (\gamma - \phi)x^s_{gm}$, where the intercept is $(p_{gm} - p_t + p^s_t)$ and the slope is

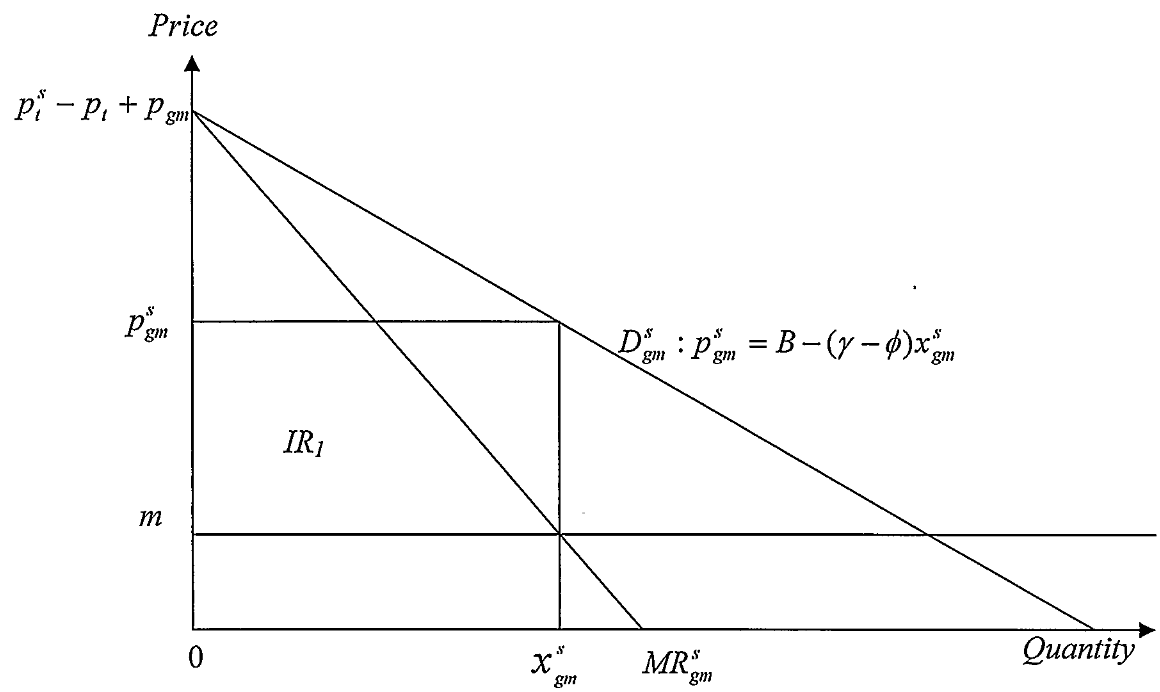

Figure 3.3: Production and pricing of GM seed under perfect enforcement of IPRs

$-(\gamma - \phi)$. For notational simplicity, the intercept is denoted by $B = (p_{gm} - p_t + p^s_t)$. A glossary of other notation used in each of the analytical cases (i) through (viii) appears as the List of Symbols and Abbreviations (page xii). Since the innovator is a monopolist, the profit maximizing price – quantity combination is determined at the intersection of marginal revenue and marginal cost functions. Demand and marginal revenue functions are denoted by the curves D^s_{gm} and MR^s_{gm} respectively; m is the constant marginal cost. Equilibrium price and quantity are p^s_{gm} and x^s_{gm} respectively. The foreign innovator derives rent equal to the rectangular area, denoted by IR_1 in the figure. Formally, the level of surplus earned by the innovator which is referred to as the innovator's rent, IR_1, is given by

$$IR_1 = (p^s_{gm} - m) \times x^s_{gm} \qquad (3.8),$$

and is identical to π defined earlier in describing the innovator's problem.
These results match exactly those of Giannakas (2002) in his benchmark case of IPRs under perfect enforcement. Giannakas' (2002) findings are replicated in equations (3.6) and (3.7) so that comparison of these to the results derived later in the chapter would be easier. As mentioned earlier, unlike Giannakas' (2002) the present analysis does not assume any one-to-one correspondence between the input and output of GM variety.

In the first stage of the game, i.e., the last stage in the backward induction method, domestic government makes its move. Government as a social planner aims at maximizing social welfare. For analytical simplicity, welfare arising from all other sectors of the economy is assumed not to affect, nor to be affected by, the contribution from this sector. Implicit here are the assumptions of a strict utilitarian social welfare function and the assumption that gains in this sector are separable from those in other sectors. In Giannakas' (2002) benchmark case, the relevant portion of the social welfare function (W_1) consists simply of the producers' surplus (PS_1) in the developing country given by the area under the dotted lines in Figure 3.2. Since the negative externality has not yet been considered, it does not affect the social welfare function. Resultantly, the government does not have any instrument to control the level of social welfare in this case. Therefore, the level of social welfare in this case is given by

$$W_1 = PS_1 = \int_0^{A_{gm}} \Pi^h_{gm}\, dA + \int_{A_{gm}}^1 \Pi_t dA = p_t - p^s_t + \frac{\gamma}{2} + \frac{(B-m)^2}{8(\gamma - \phi)} \qquad (3.9),$$

where $B = (p_{gm} - p_t + p_t^s)$ (and this derivation is presented in Section 3.1(B) of Appendix A).

In this case, government's problem is straight forward as the government is able to ensure complete enforcement of the innovator's rights. In this case, since market failure arising from negative externalities associated with the GM variety is assumed away, government does not interfere with the market for that purpose and therefore, government does not have any choice variable. Thus, in case (i) the welfare component, W_1 is an exogenous parameter in the sense that it is determined by factors which are outside government's control. In later sections it can be observed that, in general, the government's problems are more complex as maximization of social welfare involves balancing the competing interests of the producers and the innovator. In particular, in subsequent cases, it will be observed that government's policy choice affects the levels of producers' surplus earned by the domestic crop producers and the levels of economic rent repatriated by the foreign monopolist and thus affects the overall social welfare of the developing country. Government's problems in those cases consist of constrained optimization.

3.1.2 Case (ii): Negative externalities occur, no policy measures adopted yet

The current analysis extends Giannakas' (2002) model to include a new GM crop variety that may also bring disadvantages to the adopting country. In this section, a general negative external effect of biotechnology is incorporated into the model. External effects associated with GM seed usage, valued in monetary terms, are denoted by D_2^{PE} and are defined as

$D_2^{PE} = c \times x_{gm}^s$ (3.10), where c is a constant.

There can be three possibilities based on equation (3.10). First, consider the case when the constant c assumes a strictly positive value, i.e. $c > 0$. This implies that the GM seed usage creates negative externality or damage. Damages are assumed to be positively related to the quantity of GM seed, implying the higher the level of GM seed used, more are the realized associated negative externalities. External effects of this category can be related to the loss of biodiversity due to the spread of monoculture, loss of traditional knowledge and the risk associated to human health from the consumption of GM food. The second possibility is that of $c = 0$, implying that the use of GM seed does not give rise to any externalities. Finally, there can be positive externalities arising from GM seed usage, in which case, the constant c will be strictly negative, i.e., $c < 0$. Positive externalities arise when application of agricultural biotechnology results in increased pest resistance leading to less spillover damage from the use of pesticides, as an example.

In the current analysis, the first two possibilities are studied in considerable detail, i.e., $c \geq 0$. The detailed examination of positive externality can be considered as an extension of the current research and may be incorporated as part of the future research.

For meaningful analysis, it is assumed that the constant c is small enough, leaving the monetary value of the externality at a low level, so that even after the introduction of the public policies, such as tax or subsidy discussed later in the chapter, the optimal quantity of GM seed usage remains positive. With a high c, leading to a high monetary value of externality, introduction of corrective policy tools might lead to zero GM seed usage as the optimal outcome. Presumably, the decision to admit each GM variety and to enforce its IPR was conditioned on some assessment that the socially optimal quantity would be positive.

In this case, social welfare (W_2) changes to

$$W_2 = PS_2 - D_2^{PE} \qquad (3.11).$$

Clearly, social welfare diminishes here as compared to case (i) for any $D_2^{PE} > 0$. Equilibrium price and quantity of GM output remain unaffected, since, by assumption, the government does not take any corrective measure in response to the negative externality.

The assumption about the externality that is made in (3.10) is not general to all GM crops. By counter-example, the monetary value of the externality can assume different functional forms. For example, think about a third country that imports crops from the developing country considered here provided that the exporter is "GM-free." This 'third country' might reduce significantly or stop the imports altogether, since the developing country started importing the GM variety. In this case, the negative externality would be a discontinuous function, and not proportional to x^s_{gm} as in (3.10).

3.1.3 Case (iii): Negative externalities occur, corrective tax imposed per unit of GM seed purchased as a policy measure

If the GM variety brings some associated disadvantage, denoted by D_3^{PE}, then government's optimal policy response is also altered. Here, the government is assumed to introduce a tax per unit of GM seed purchased, τ_0, so as to *internalize* the externality to the extent possible. Following the method of backward induction, the producer's problem is analyzed first. Equation (3.2) can be re-written as

$$\widetilde{\Pi}^h_{gm} = p_{gm} - \widetilde{p}^s_{gm} + \phi A \qquad (3.12),$$

where: $\widetilde{p}^s_{gm} = \hat{p}^s_{gm} + \tau_0$, $\widetilde{p}^s_{gm}$ is the GM seed price inclusive of tax faced by the producers and $\hat{p}^s_{gm}$ is the price (net of tax) set by the innovator in response to a fall in its demand induced by the tax on its product. Net returns from the traditional crop variety remain unaltered. Figure 3.4 illustrates the producers' net returns from different crop varieties. The new level of GM output is given by

$$\widetilde{A}_{gm} = \widetilde{x}^s_{gm} = \frac{(p_{gm} - \widetilde{p}^s_{gm}) - (p_t - p^s_t)}{\gamma - \phi} \qquad (3.13).$$

Due to the imposition of the tax (τ_0), net returns from GM crops drop from Π^h_{gm} to $\widetilde{\Pi}^h_{gm}$. This in turn implies that a greater fraction of producers choose production of the traditional crop variety as the net returns from the traditional crop are higher for them. This is evident from the dotted portions of the Π_t curve in the pre-tax and post-tax scenarios in the figure. The quantity of traditional seed usage increases from x^s_t to $\widetilde{x}^s_t$ and GM seed usage decreases from x^s_{gm} to $\widetilde{x}^s_{gm}$.

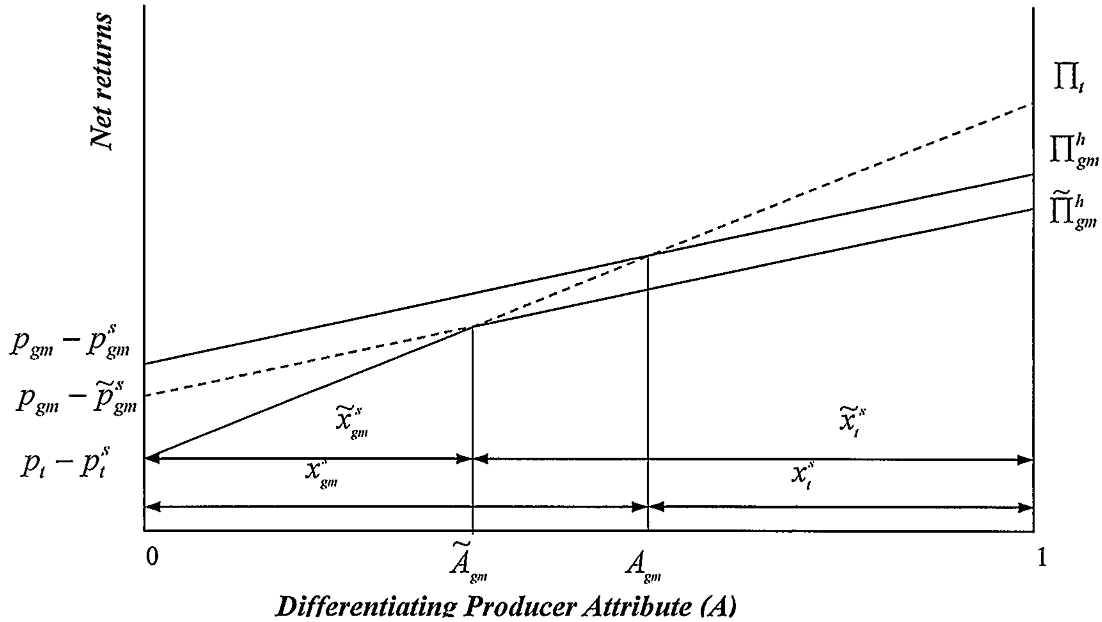

Figure 3.4: Production decision and producers' net returns under perfect enforcement of IPR with tax (τ_0) per unit of GM seed purchased

Consider the innovator's problem in the presence of a tax, following the approach of backward induction. The innovator's optimal pricing strategy in the face of the corrective tax will be fully informed by this knowledge of how individual producer's seed purchases will respond. The innovator's objective here is to maximize profits through determining the price of the GM seed. Formally, innovator's problem can be stated as

$$\max_{\hat{p}^s_{gm}} \pi = (\hat{p}^s_{gm} - m)\tilde{x}^s_{gm},$$

where $\tilde{x}^s_{gm}$ is the post-tax equilibrium quantity of GM seed used. Solving the innovator's problem (derivations are presented in Section 3.1(C) of Appendix A) the equilibrium price and quantity are calculated to be

$$\hat{p}^s_{gm} = \frac{p_{gm} - p_t + p^s_t + m - \tau_0}{2} = \frac{B + m - \tau_0}{2} \qquad (3.14),$$

$$\tilde{p}^s_{gm} = \frac{p_{gm} - p_t + p^s_t + m + \tau_0}{2} = \frac{B + m + \tau_0}{2} \qquad (3.15)$$

and

$$\widetilde{x}^s_{gm} = \frac{p_{gm} - p_t + p^s_t - m - \tau_0}{2(\gamma - \phi)} = \frac{B - m - \tau_0}{2(\gamma - \phi)} \qquad (3.16).$$

Comparing these results with those of Giannakas (2002), i.e., with those of case (i) in the present analysis, it is observed that the equilibrium price of GM seed set by the innovator (net of tax) decreases by $\frac{\tau_0}{2}$ in the post-tax scenario (refer to equations (3.6) and (3.14) and note that p_{gm}, p_t, p^s_t and m are fixed constants in each case). On the other hand, the equilibrium price of GM seed faced by the producers (inclusive of tax) increases by $\frac{\tau_0}{2}$ in the post-tax case (equations (3.6) and (3.15)). The equilibrium quantity of GM seed also reduces by $\frac{\tau_0}{2(\gamma - \phi)}$ in absolute magnitude, due to the imposition of tax (refer to equations (3.7) and (3.16)).

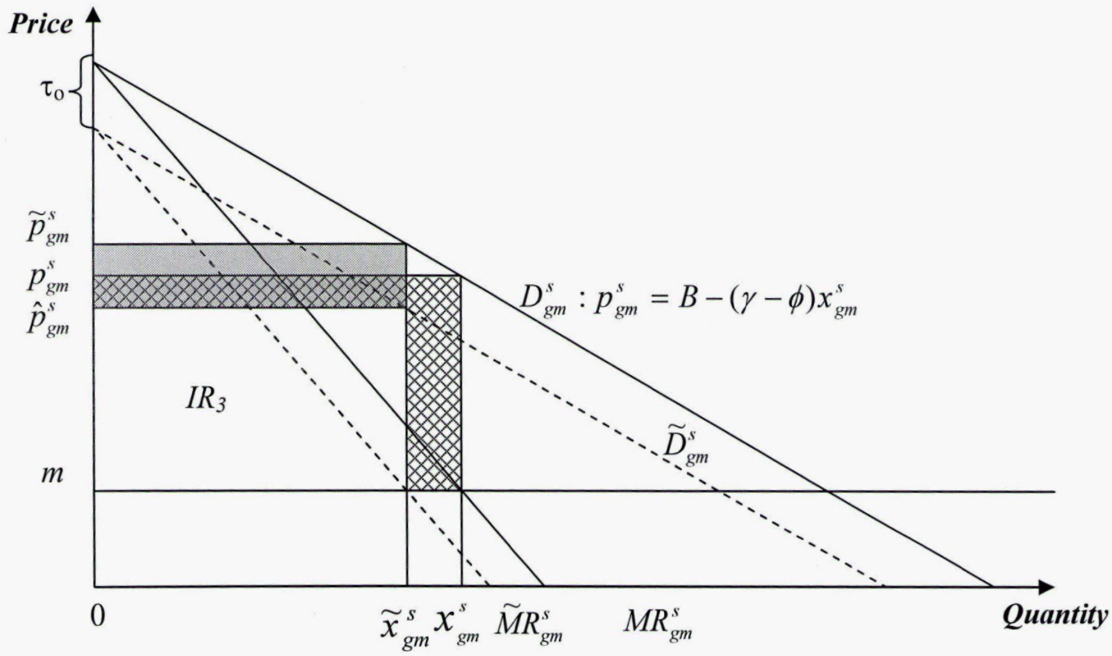

Figure 3.5: Production and pricing of GM seed under perfect enforcement of IPRs and loss in innovator's rent due to taxation

Figure 3.5 shows the determination of equilibrium price and quantity by the foreign innovator in the post-tax situation. Due to the imposition of tax at rate τ_0 per unit of GM seed purchased, producers reduce their willingness to pay (net of tax) for GM seed, shown by the inward shift of the demand curve from D^s_{gm} to $\widetilde{D}^s_{gm}$. This leads to a fall in the innovator's rent by the 'L' shaped hatched area shown in the figure. The rectangular area (shaded grey) is the tax revenue TR_3 earned by the domestic government in the GM seed market.

In this case, government's decision, in the final stage of backward induction is not as simple as it was in case (i). Here, government needs to decide on the optimal level of tax (τ_0^*) to be imposed. The objective is to maximize social welfare, W_3, which consists of producers' surplus (PS_3) less negative externalities arising from GM crops (D_3^{PE}), plus the tax revenue (TR_3). Although the purpose of the tax is to correct the externality, tax revenues raised also contribute to social welfare (and are not lost to society when tax payments reduce producers' surplus and innovator's profit). The constraint in the optimization problem is a minimum innovator rent implying that the innovator's rent (IR_3) should be greater than some minimum level, r_3, so that the innovator finds it profitable to stay in the market. Government's problem can be presented as

$$\max_{\tau_0} W_3 = PS_3 - D_3^{PE} + TR_3,$$
$$subject\ \ to\ \ IR_3 > r_3\ \ (\geq 0).$$

Producer's surplus is given by the area below the dotted lines in Figure 3.4

$$PS_3 = \int_0^{\widetilde{A}_{gm}} \widetilde{\Pi}^h_{gm} dA + \int_{\widetilde{A}_{gm}}^1 \Pi_t \, dA = p_t - p_t^s + \frac{\gamma}{2} + \frac{(B - m - \tau_0)^2}{8(\gamma - \phi)}$$

(3.17) (the derivation is shown in Section 3.1(D) of Appendix A). Adverse effects of GM seed usage are measured using the damage function given by

$$D_3^{PE} = c \times \widetilde{x}^s_{gm} \qquad (3.18).$$

Tax revenue earned by the government is specified as

$$TR_3 = \tau_0 \times \tilde{x}^s_{gm} \qquad (3.19).$$

Innovator's rent (*IR₃*) is the area shown in Figure 3.5

$$IR_3 = \left(\hat{p}^s_{gm} - m\right) \times \tilde{x}^s_{gm} \qquad (3.20).$$

Solving government's problem by using Kuhn – Tucker conditions, the optimal level of tax (derivations are presented in Section 3.1(D) of Appendix A) is

$$\tau_0^* = \frac{1}{3}(p_{gm} - p_t + p_t^s + 2c - m) = \frac{1}{3}(B + 2c - m) \qquad (3.21).$$

In this section, a detailed description of the perfect enforcement of IPR regime has been presented. In cases (i) and (ii), the government does not implement a corrective tax, whereas in case (iii) the optimal rate of tax is reached by backward induction. In each case, the innovator's optimal choice of price and quantity for the GM seed variety allows a determination of the quantities of seed of each crop variety that are used by heterogeneous producers. Knowledge of the cost of the externality allows a description of the level of social welfare that is achieved by domestic residents from activities in this sector of the agricultural economy.

In the next section, the imperfect enforcement regime is introduced and the use of a tax as government's policy measure is considered. As earlier, the level of enforcement is taken to be exogenous. It will be observed that some of the findings of this section remain relevant in the next section as well. There will be some additional developments owing to the complex nature of the enforcement regime.

3.2 Imperfect enforcement of intellectual property rights in the developing country

In this section the case of IPRs infringement in the developing country is considered. In particular, the crop producers can acquire GM seeds without paying the monopolist's price for them. Suppose crop producers are able to use various illegal means such as reverse engineering, black marketing and harvesting seeds from last season's GM crops.

That is, the assumption that the GM seeds possess a 'terminator gene' is relaxed.[1] In this case, problems of informational asymmetry come up as the individual producer's action cannot be directly observed even though it is clear how they might behave in aggregate. Equation (3.22) gives the *expected* net returns function of the producers (who are assumed to be risk neutral) for a unit of genetically modified crop produced using seeds acquired illegally

$$\Pi_{gm}^{c} = p_{gm} + \phi A - \delta(A)\rho - m \qquad (3.22).$$

In contrast to Giannakas' (2002) modeling, a seed cost equivalent to the marginal cost of the innovator is attached to acquiring GM seeds illegally by the domestic crop producers. In contrast to the approach used by Giannakas (2002), the assumption here is that illegally acquired GM seeds would not be completely costless. In the current analysis, it is assumed that the crop producers are as efficient as the foreign innovator in acquiring GM seeds (illegally) and therefore they face the marginal cost, *m*.

In equation (3.22) $\delta(A)$ is the probability of the developing country government identifying "cheating" (infringement) on the part of some producers, with ($0 \leq \delta(A) \leq 1$), and ρ is the fixed (per unit) penalty imposed (with certainty) on those producers who are caught infringing. The value of $\delta(A)$ depends upon the general probability that the producers will be audited (δ_0) and the producer-specific characteristics, denoted by the differentiating attribute A. As in Giannakas (2002), enforcement authorities are more effective in their enforcement efforts against those producers with higher A values, and this is well known by all. For simplicity, similar to Giannakas (2002), a linear function is assumed that relates δ, δ_0 and A, i.e., $\delta = \delta_0 A$. In the present study, for analytical purposes, δ_0 is assumed to be fixed. This is a major difference between the current

[1] When a terminator gene is employed, the net returns functions of GM crop (legal and illegal) could also be thought of as $\Pi_{gm}^{h} = Z_h(p_{gm} + \phi A) - p_{gm}^{s}$ and $\Pi_{gm}^{c} = Z_c(p_{gm} + \phi A) - \delta_0 \rho A - m$ respectively, where, Z is the genetic productivity parameter. In case of 'terminator gene', $Z_h = 1$ and $Z_c = 0$, and risk neutral producers would never use illegal seed.

model and that of Giannakas (2002). Giannakas (2002) took δ_0 as endogenous to the model by enabling the domestic government to choose the level of IPRs enforcement whereas in the current exposition, δ_0 is exogenous. This assumption will help derive the optimal tax or subsidy levels (discussed later) while other parameters remain unchanged.

Under perfect enforcement, $\delta_0 = 1$, implying cheating is always detected. Even with $\delta_0 = 1$, the government must set an infinitely high penalty, i.e., $\rho = \infty$, in order to ensure perfect enforcement of IPRs unless the variety in question possesses a terminator gene. Under perfect enforcement, the net return from producing a GM crop illegally is zero for all levels of differentiating producers' attribute, A. However, to avoid such limiting assumptions, under perfect enforcement it was assumed that the GM seeds possess a 'terminator gene.'

Under imperfect enforcement, $0 \leq \delta_0 < 1$, implying the probability of getting caught (if cheating) is less than 100%. This could be attributed to auditing on the part of the government being costly, so that the government cannot guarantee full enforcement of IPRs. Moreover, the penalty on cheating when caught is not too high, i.e., $\rho < \infty$. Therefore, there is always at least one producer for whom cheating yields higher net returns than using purchased seeds. In this case, the analysis is based on the game tree shown in Figure 3.6 where the government in the developing country enforces IPRs imperfectly. The problem is solved using the method of backward induction.

As is evident from the beginning node of Figure 3.6, government in the developing country enforces the foreign innovator's rights imperfectly. As before, it has either of two alternative tools to counter the negative externalities from GM crop production: tax and subsidy. Observing the government's move, the foreign innovator chooses the price of GM seed for the developing country market. Producers in the developing country decide on which crop to produce, GM or traditional, based on the moves of the previous players. Under imperfect IPRs enforcement, producers have an additional option of producing GM crop using seed acquired illegally, i.e., the option of cheating. Payoffs of all the players are shown in Figure 3.6.

For analytical purposes, four cases under imperfect enforcement scenario are considered and are shown in Table 3.2. In this section, cases (v) through (vii) are described; case (viii) is discussed later in section 3.4.

Enforcement Regime	Analytical cases
Imperfect Enforcement of IPR	Case (v): No externality, no policy measures adopted
	Case (vi): Negative externalities occur, no policy measures adopted yet
	Case (vii): Negative externalities occur, corrective tax imposed per unit of GM seed purchased as a policy measure
	Case (viii): Negative externalities occur, corrective subsidy levied per unit of traditional seed purchased as a policy measure

Table 3.2: Description of various cases for analyzing imperfect enforcement of IPRs

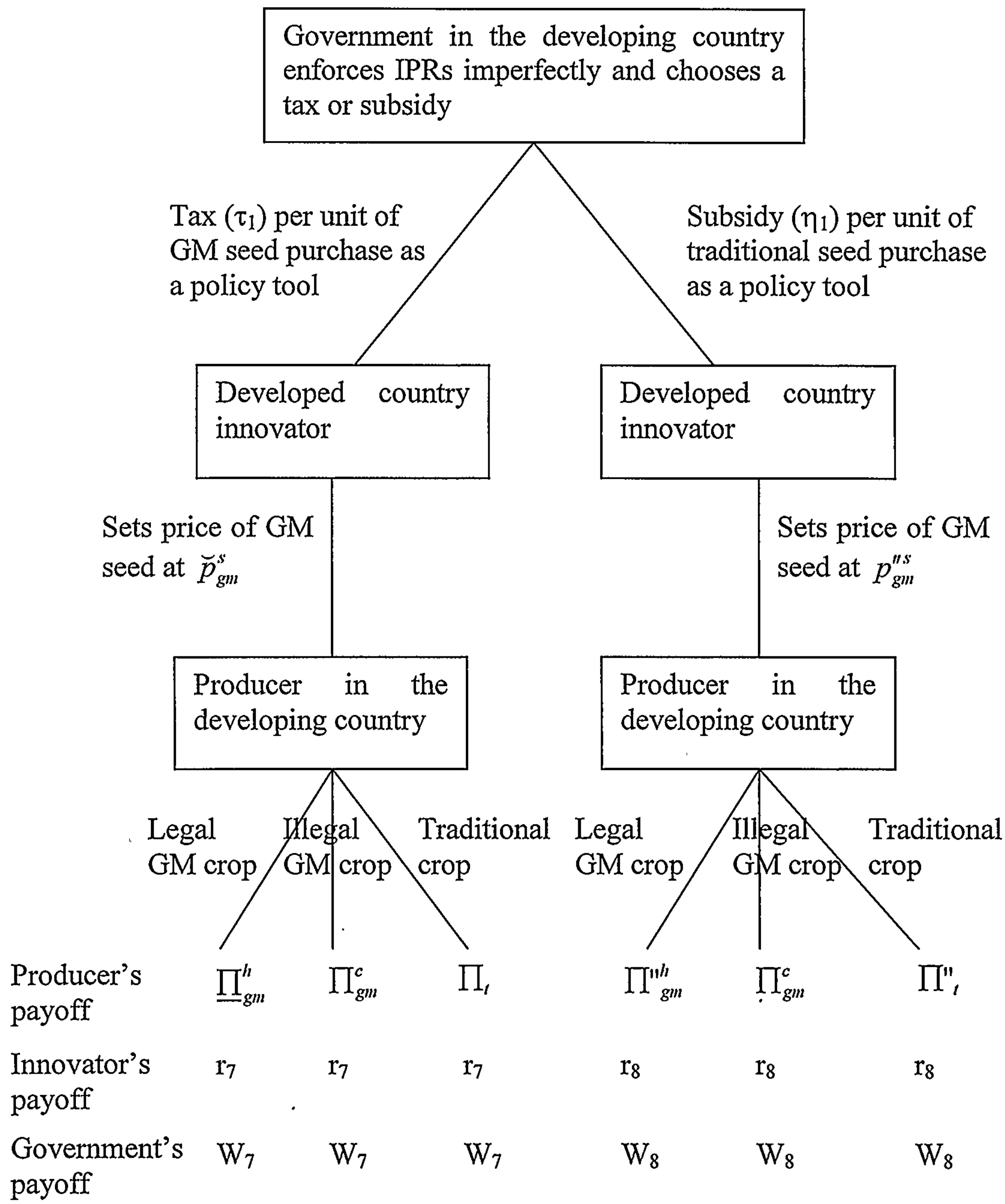

Figure 3.6: Game tree illustrating imperfect enforcement of IPRs

3.2.1 Case (v): No externality, no policy measures adopted

This case is again similar to the imperfect enforcement of IPRs in Giannakas (2002). Following the method of backward induction, the analysis begins at the last step with the producers' problem. Since perfect monitoring on the part of the government is not in effect, a new profit alternative for some producers is created, based on their differentiating attribute A. There are some producers who can get away with acquiring GM seed through illegal means without being caught. This in turn depends on the value of δ_0, the probability that the producer will be investigated for cheating. If δ_0 is low, a larger number of producers use the illegal means whereas, if δ_0 is high, a lesser number of producers make this choice as they may have to pay the penalty ρ. The illegal component of GM output can be identified in Figure 3.7 below. Net returns from the GM crop produced using illegally acquired seed are given by:

$$\Pi^c_{gm} = p_{gm} + \phi A - \delta_0 \rho A - m \qquad (3.22A).$$

Equation (3.2) is re-written as

$$\overline{\Pi}^h_{gm} = p_{gm} - \overline{p}^s_{gm} + \phi A \qquad (3.23)$$

where $\overline{p}^s_{gm}$ is the price of GM seed set by the monopolist (innovator) in the GM seed market in the imperfect enforcement scenario and $\overline{\Pi}^h_{gm}$ is the resultant net returns function of the producers. Net returns from traditional crop production are given by equation (3.1) as before

$$\Pi_t = p_t - p^s_t + \gamma A \qquad (3.1).$$

From Figure 3.7 it is observed that the producers with differentiating attribute in the interval $A \in [0, A_{gm})$ prefer to produce the GM crop as its net return is higher in this region. Producers with $A \in (A_{gm}, 1]$ produce the traditional crop since, Π_t, the net return from the traditional crop is the highest here, as shown by the dotted portion of Π_t. A closer examination of the GM crop region reveals that the producers with differentiating attribute in the interval $A \in [0, A^c_{gm})$ produce GM crop using illegally acquired seed since

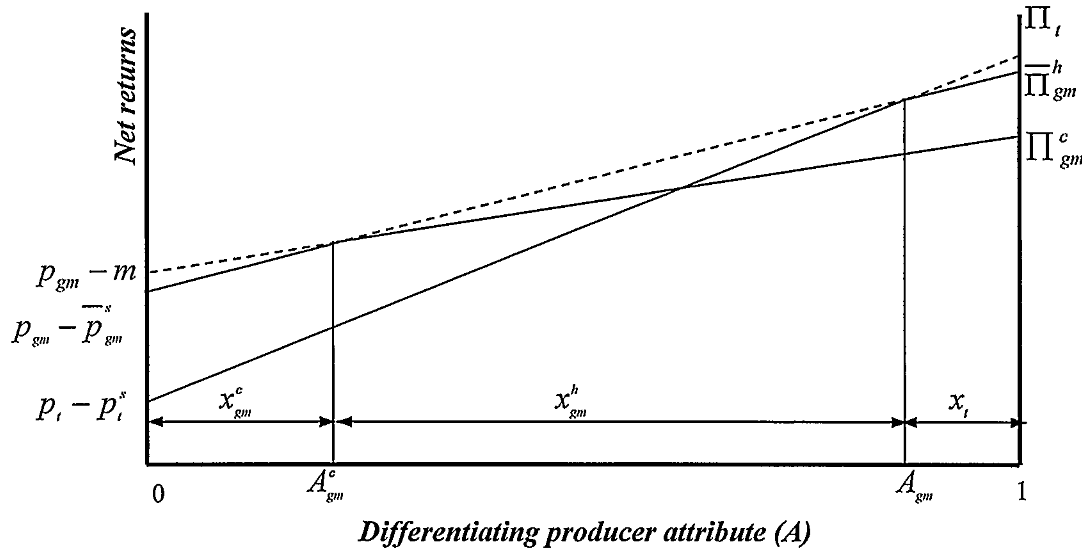

Figure 3.7: Producers' net returns under imperfect enforcement of IPRs

the net return from illegal GM output is higher denoted by the dotted portion of Π^c_{gm}. Those with $A \in (A^c_{gm}, A_{gm})$ produce GM crop with legally purchased seed, since the net return from legal GM crop production is the highest here, shown by dotted portion of $\overline{\Pi}^h_{gm}$. Producers at A^c_{gm} are indifferent between producing a unit of illegal and legal GM crop and those at A_{gm} are indifferent between producing a unit of (legal) GM and traditional crop varieties. Thus, solving for different producer attributes one obtains the following

$$A^c_{gm} = \frac{\overline{p}^s_{gm} - m}{\delta_0 \rho} \qquad (3.24),$$

implying that all else being equal, more producers use illegal seed the higher is the legal seed price and the lower is the expected cost of getting caught. Similarly,

$$A_{gm} = \frac{p_{gm} - p_t + p_t^s - \overline{p}_{gm}^s}{\gamma - \phi} \qquad (3.25),$$

implies that all else equal, more producers use GM seed the lower is the legal GM seed price and the price of the traditional crop output, or the higher is the traditional seed price or GM crop price.

In the second stage of backward induction, the innovator's problem is considered. The foreign innovator, as a monopolist in the seed market, aims at maximizing profits. Presenting the innovator's objective in formal terms gives,

$$\max_{\overline{p}_{gm}^s} \pi = (\overline{p}_{gm}^s - m)x_{gm}^h .$$

Solving the innovator's problem (derivations are presented in Section 3.2 (A) of Appendix A), the price of GM seed is found to be

$$\overline{p}_{gm}^s = \frac{\delta_0\rho(p_{gm} - p_t + p_t^s) + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0\rho)} + \frac{m}{2} = \frac{\delta_0\rho B + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0\rho)} + \frac{m}{2} \qquad (3.26),$$

the quantity of legal GM seed is

$$x_{gm}^h = \frac{(p_{gm} - p_t + p_t^s - m)}{2(\gamma - \phi)} = \frac{(B - m)}{2(\gamma - \phi)} \qquad (3.27)$$

and the quantity of GM seed acquired illegally is given by

$$x_{gm}^c = \frac{(p_{gm} - p_t + p_t^s - m)}{2(\gamma - \phi + \delta_0\rho)} = \frac{(B - m)}{2(\gamma - \phi + \delta_0\rho)} \qquad (3.28),$$

where, $B = p_{gm} - p_t + p_t^s$. These results differ slightly to those in Giannakas (2002) because of the assumption of a cost associated with illegally acquired GM seed. In particular, domestic producers face a cost equivalent to the marginal cost of the innovator, m while using illegal GM seeds. When m is set equal to zero, the results exactly match those of Giannakas (2002). In addition, this model differs from that of Giannakas (2002) on some other issues as well with the variations being the assumption on δ_0, namely, δ_0 is exogenous in the present analysis and that the assumption (in

Giannakas, 2002) of a one-to-one correspondence between levels of GM input and output is dropped.

The social welfare function in this case consists of the producers' surplus PS_5 less a cost associated with IPRs enforcement EC incurred by the domestic government plus the expected revenue earned through the penalty imposed on the producers found cheating, F_5. Thus,

$$W_5 = PS_5 - EC + F_5 \qquad (3.29),$$

where PS_5 (derivation is provided in 3.2(A) of Appendix A) is the area beneath the dotted lines in Figure 3.7 above, such that

$$PS_5 = \int_0^{A^c_{gm}} \Pi^c_{gm} dA + \int_{A^c_{gm}}^{A_{gm}} \overline{\Pi}^h_{gm} dA + \int_{A_{gm}}^{1} \Pi_t dA$$
$$= p_t - p^s_t + \frac{\gamma}{2} + \frac{(B-m)^2}{2(\gamma - \phi + \delta_0 \rho)} + \frac{\delta_0 \rho (B-m)^2}{8(\gamma - \phi)(\gamma - \phi + \delta_0 \rho)} \qquad (3.30).$$

Enforcement cost is assumed to increase with higher δ_0 at a constant rate, α, so that

$$EC_5 = \alpha \delta_0 + \beta \qquad \alpha > 0, \quad \beta > 0 \quad (3.31).$$

Expected public revenue from the penalty, F_5, can be thought of as a function of the producers' probability of getting caught while cheating ($\delta_0 A$) and the penalty (ρ)

$$F_5 = \rho \int_0^{A^c_{gm}} (\delta_0 A) dA \qquad (3.32).$$

Now, all the components of social welfare function, except for the enforcement costs (EC_5) are *expected* values (unlike perfect enforcement) as there is a probability δ_0 associated with these. Therefore, government's payoff in this case W_5 is also an *expected* level of social welfare. A decision to maximize expected social welfare involves an assumption about risk neutrality of the government on society's behalf. In case (v), government has no instruments to influence W_5, which is thus exogenous.

3.2.2 Case (vi): Negative externalities occur, no policy measures adopted yet

In a manner analogous to section 3.1, case (ii), consider this intermediate stage where the damaging effects of biotechnology have been recognized, but policy instruments have not been used yet. The only resultant change in this case over case (v) is reflected in government's social welfare function. Social welfare, W_6, includes the damage component D_6^{IE} in the imperfect enforcement scenario. By assumption, W_6 is exogenous and not influenced by government's policy or action. It is the "do nothing" case. The level of social welfare in this case is given by

$$W_6 = PS_5 - D_6^{IE} - EC_5 + F_5 \qquad (3.33).$$

Valuation of the negative externality in this case changes in that it incorporates both legal and illegal components of GM seed usage

$$D_6^{IE} = c(x_{gm}^h + x_{gm}^c) \qquad (3.34).$$

This implies that the (external) damage caused under the imperfect enforcement scenario is more than that under the perfect enforcement scenario, provided that $(x_{gm}^h + x_{gm}^c) > x_{gm}^s$.

3.2.3 Case (vii): Negative externalities occur, corrective tax imposed per unit of GM seed purchased as a policy measure

This is the scenario in which production of the GM crop gives rise to negative externalities and in response, government policy changes to reduce such inefficiencies. Consider once again the case of a tax (τ_1) per unit of GM seed purchased. Note that the tax can only be imposed on (legal) market purchases from the innovator and not on GM seed acquired illegally. Beginning with the producers' problem using the backward induction method, it is observed that in this sequential game, the producers in the developing world aim at increasing their net returns from various crops (GM or non-GM). The price of GM seed, inclusive of tax is $\underline{p}_{gm}^s = \breve{p}_{gm}^s + \tau_1$, $\breve{p}_{gm}^s$ is the price of GM seed set by the innovator in the presence of demand shrink due to the tax and cheating. Thus, equation (3.2) that describes net returns from legal use of GM seed now becomes

$\underline{\Pi}^{h}_{gm} = p_{gm} - \underline{p}^{s}_{gm} + \phi A$ (3.35).

The net returns associated with traditional and illegally produced GM crop are given by equations (3.1) and (3.22*A*) respectively

$\Pi_{t} = p_{t} - p^{s}_{t} + \gamma A$ (3.1) and

$\Pi^{c}_{gm} = p_{gm} + \phi A - \delta_{0}\rho A - m$ (3.22*A*).

Proposition 1: Producers produce the GM crop with illegally used seed if and only if the (tax inclusive) price of the GM seed is greater than the expected penalty from cheating plus that seed's marginal cost.

Proof: This proposition was originally developed by Giannakas (2002) for the case where there are no government policy measures, i.e., case (v) under imperfect enforcement. Here, the proposition is shown to be valid with a case of tax per unit of GM seed as a policy instrument to take care of the negative externality, and with the addition of seed cost, *m*.

The producer with characteristic *A* uses GM seed illegally when the expected net returns from producing GM crop illegally are more than those from legal GM crop production, i.e., $\Pi^{c}_{gm} > \underline{\Pi}^{h}_{gm}$. When this inequality holds, this implies, $p_{gm} + \phi A - \delta_{0}\rho A - m > p_{gm} - \underline{p}^{s}_{gm} + \phi A$;

or, in other words, $\underline{p}^{s}_{gm} > \delta_{0}\rho A + m$.

The left hand side in the above inequality condition is the price of GM seed (inclusive of tax) faced by the producers and the right hand side gives the expected penalty plus the seed cost. Thus, only those producers cheat for whom the expected penalty to be paid on getting caught plus *m* is less than the price of GM seed charged by the innovator.

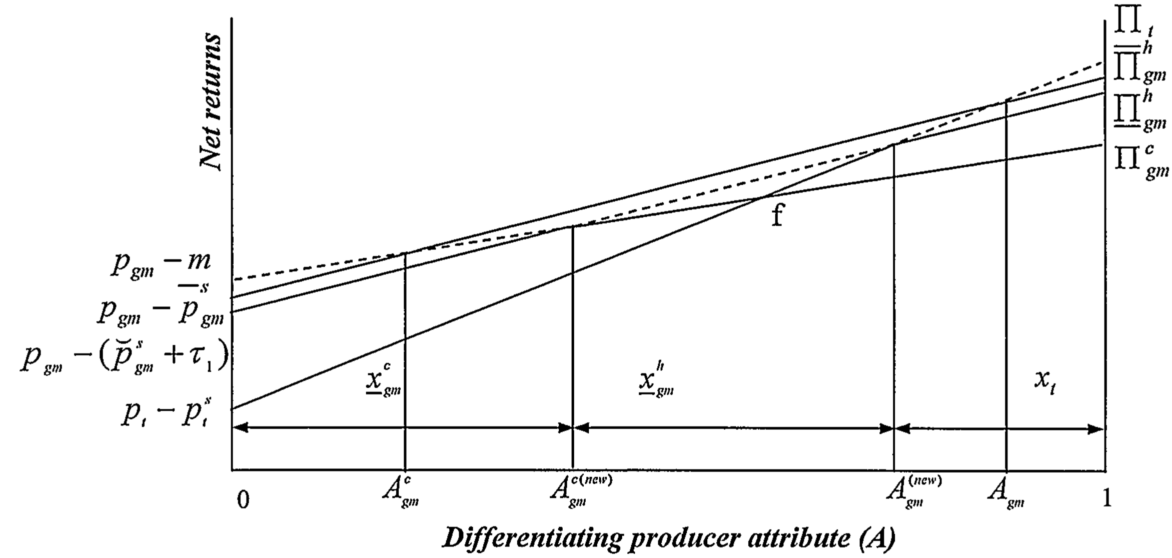

Figure 3.8: Producer's net returns under imperfect enforcement of IPRs with 'low' tax

The net returns functions of the producers can be shown using Figure 3.8. Due to imposition of tax, net returns from the production of legal GM output decrease as can be seen from the downward shift in the $\overline{\Pi}^h_{gm}$ function to $\underline{\Pi}^h_{gm}$. This in turn reduces the demand for GM seed and thus the quantity of GM seed exchanged. This will be more obvious when the innovator's problem is discussed later in this section.

Proposition 2: The level of corrective tax has a maximum critical value below which all three seed varieties, namely traditional, legal GM and illegal GM, prevail in the market.

Proof: To derive this proposition, it is useful to introduce the critical point denoted *'f'* in Figure 3.8. Examining Figure 3.8 more closely, it can be observed that if the function $\underline{\Pi}^h_{gm}$ passes below *'f'*, the net returns function for legal GM seed, $\underline{\Pi}^h_{gm}$ becomes irrelevant. In such cases, net returns from use of either the illegal GM seed or the traditional seed are always higher than those from legal GM seed. This scenario is discussed in more detail in Proposition 3. Consider here the case with a 'low' level of corrective tax, implying that the tax rate τ_1 is set such that $\underline{\Pi}^h_{gm}$ remains above the critical point 'f', and that there are always at least some crop producers who choose to produce their crop using purchased GM seed. The producers' attribute A at the critical point 'f', denoted A_f, is derived by equating Π_t and Π^c_{gm} at A_f, and is given by

$$A_f = \frac{p_{gm} - p_t + p^s_t - m}{\gamma - \phi + \delta_0 \rho} = \frac{B - m}{\gamma - \phi + \delta_0 \rho} \qquad (3.36).$$

For a 'low' level of tax, $\underline{\Pi}^h_{gm}$ at A_f should be greater than Π^c_{gm} at A_f. In other words, using equations (3.35) and (3.22A), the condition for a 'low' level of tax is $p_{gm} - \underline{p}^s_{gm} + \phi A_f > p_{gm} + \phi A_f - \delta_0 \rho A_f - m$, which on simplification yields $\underline{p}^s_{gm} < \delta_0 \rho A_f + m$. As defined earlier, $\underline{p}^s_{gm}$ is the price of GM seed inclusive of tax, i.e., $\underline{p}^s_{gm} = \breve{p}^s_{gm} + \tau_1$. Substituting the values of $\underline{p}^s_{gm}$ and A_f (from equation (3.36)) into the above inequality, a 'low' level of tax implies $\tau_1 < \dfrac{(p^s_t - p_t + p_{gm})\delta_0 \rho + m(\gamma - \phi)}{\gamma - \phi + \delta_0 \rho} - \breve{p}^s_{gm}$.

Thus, when this inequality holds, the tax is 'low' and $\underline{\Pi}^h_{gm}$ lies above point 'f', as shown in Figure 3.8.

The foreign innovator's problem in the next stage of backward induction is to determine the price and quantity of the GM seed. This can be expressed as

$$\max_{\breve{p}^s_{gm}} \pi = (\breve{p}^s_{gm} - m)\underline{x}^h_{gm},$$

$$subject \quad to \quad \tau_1 < \frac{\delta_0 \rho (p_{gm} - p_t + p^s_t) + m(\gamma - \phi)}{\gamma - \phi + \delta_0 \rho} - \breve{p}^s_{gm}.$$

The constraint is derived in proposition 2 above under the '*low*' tax scenario. Solving the innovator's problem using Lagrange multiplier (derivations are presented in Section 3.2 (B) of Appendix A) the price of GM seed set by the innovator net of tax is found to be

$$\breve{p}^s_{gm} = \frac{\delta_0 \rho (p_{gm} - p_t + p^s_t) + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0 \rho)} - \frac{\tau_1 - m}{2} \qquad (3.37).$$

The price of GM seed inclusive of tax, which is faced by the producers, is given by

$$\underline{p}^{s}_{gm} = \frac{\delta_0\rho(p_{gm} - p_t + p_t^s) + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0\rho)} + \frac{\tau_1 + m}{2} \qquad (3.38),$$

the quantity of post-tax legal GM seed is

$$\underline{x}^{h}_{gm} = \frac{\delta_0\rho(p_{gm} - p_t + p_t^s - m) - \tau_1(\gamma - \phi + \delta_0\rho)}{2(\gamma - \phi)\delta_0\rho} \qquad (3.39)$$

and the quantity of post-tax GM seed acquired illegally is

$$\underline{x}^{c}_{gm} = \frac{\delta_0\rho(p_{gm} - p_t + p_t^s - m) + \tau_1(\gamma - \phi + \delta_0\rho)}{2(\gamma - \phi + \delta_0\rho)\delta_0\rho} \qquad (3.40).$$

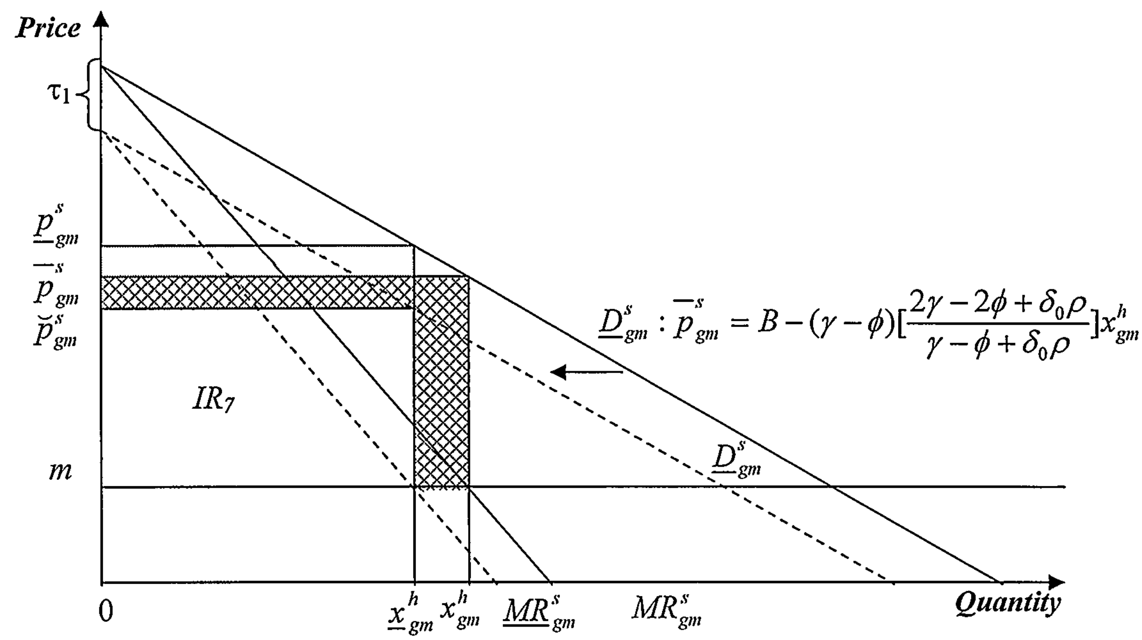

Figure 3.9: Production and pricing of GM seed under imperfect enforcement of IPRs and loss in innovator's rent due to taxation

Figure 3.9 shows the determination of the innovator's price and quantity of GM seed in the monopolistic market faced by the innovator. The pre-tax willingness to pay for the seed reduces as a result of the imposition of tax, by the amount of the tax τ_1, shown by the inward shift of the demand curve from D^{s}_{gm} to $\underline{D}^{s}_{gm}$. Innovator's rent decreases by the 'L' shaped hatched area in the figure, when the monopolist chooses the new profit maximizing. pre-tax price, $\breve{p}^{s}_{gm}$ and quantity, $\underline{x}^{h}_{gm}$. Figure 3.9 is similar to Figure 3.5, except for the notational changes.

By assumption, government takes a policy decision in this case as there is an additional source of inefficiency in the market in the form of negative external effects caused due to adoption of biotechnology. Government's objective as a social planner is to maximize social welfare (W_7) which consists of the surplus received by the domestic producers from different crop varieties (PS_7) minus the cost incurred by the government in order to enforce the innovator's rights (EC) minus the externalities D_7^{IE} stemming from GM seeds plus tax revenue (TR_7) earned by the government plus the expected revenue earned through imposition of penalty (F_7). As its only influence on the process, government determines the optimal level of tax, τ_1, that should be imposed on legal sales of GM seed by the innovator. Formally, the government's problem can be written as

$$\max_{\tau_1} W_7 = PS_7 - EC - D_7^{IE} + TR_7 + F_7,$$
$$subject \;\; to \;\; IR_7 > r_7 \;\; (\geq 0).$$

Producers' surplus, PS_7, is given by the area below the dotted line in Figure 3.8 (derivation is presented in Section 3.2(C) of Appendix A),

$$\begin{aligned} PS_7 &= \int_0^{A_{gm}^{c(new)}} \Pi_{gm}^{c} dA + \int_{A_{gm}^{c(new)}}^{A_{gm}^{(new)}} \underline{\Pi}_{gm}^{h} dA + \int_{A_{gm}^{(new)}}^{1} \Pi_t dA \\ &= p_t - p_t^s + \frac{\gamma}{2} + \frac{\tau_1^2}{8\delta_0\rho} + \frac{3(B-m)^2}{8(\gamma-\phi+\delta_0\rho)} + \frac{(-B+m+\tau_1)^2}{8(\gamma-\phi)} \end{aligned} \qquad (3.41).$$

Damages arising out of GM crop production result from both legal and illegal components of GM crop production

$$D_7^{IE} = c \times (\underline{x}^{h}_{gm} + \underline{x}^{c}_{gm}) \qquad (3.42).$$

Tax revenue (TR_7) earned by the domestic government is derived only from the legal GM component and is given by the grey shaded rectangular area in Figure 3.9,

$$TR_7 = \tau_1 \times \underline{x}^h_{gm} \qquad (3.43).$$

Expected public revenue from the penalty, F_7, can be thought of as a function of the producers' probability of getting caught while cheating ($\delta_0 A$) and the penalty (ρ),

$$F_7 = \rho \int_0^{A^{c(new)}_{gm}} (\delta_0 A) dA \qquad (3.44).$$

The monopolist's economic profits are given by

$$IR_7 = (\breve{p}^s_{gm} - m) \times (\underline{x}^h_{gm}) \qquad (3.45), \text{ where}$$

IR_7 in (3.45) is identical to π described in the innovator's problem above. The constraint in the government's problem signifies minimum innovator's rent as described in case (iii) under perfect enforcement. Solving the government's problem using Lagrange multiplier (derivations are presented in Section 3.2 (C) of Appendix A), the optimal rate of tax is

$$\tau_1^* = \delta_0 \rho \left(\frac{4(p_{gm} - p_t + p_t^s) + 2c - 2m}{2\gamma - 2\phi + 3\delta_0 \rho} + \frac{-(p_{gm} - p_t + p_t^s) + m}{\gamma - \phi + \delta_0 \rho} \right)$$

$$= \delta_0 \rho \left(\frac{4B + 2c - 2m}{2\gamma - 2\phi + 3\delta_0 \rho} + \frac{-B + m}{\gamma - \phi + \delta_0 \rho} \right) \qquad (3.46).$$

In order to verify that this is a 'low' tax, τ_1^* in (3.46) is subtracted from the critical level of tax τ_f, derived in proposition 2. Thus, $\tau_f - \tau_1^* = \frac{2(B-m)\delta_0 \rho}{\gamma - \phi + \delta_0 \rho} - \delta_0 \rho \left(\frac{4B + 2c - 2m}{2\gamma - 2\phi + 3\delta_0 \rho} \right)$, where, $B = p_{gm} - p_t + p_t^s$. The sign of this expression depends on c. Assuming c to be small enough, i.e., the level of externality is small, $\tau_f - \tau_1^*$ should be positive. For this, the critical value of c is such that $c < \left[\frac{\delta_0 \rho (B - m)}{\gamma - \phi + \delta_0 \rho} \right] - m$. If c were larger a higher tax rate could be charged and no legal GM seed would be sold.

Proposition 3: The 'low' level of corrective tax on legally acquired GM seeds reduces total GM seed usage but increases the level of illegally acquired GM seeds.

When government introduces a tax on GM seed purchased, net returns to the producers who purchase GM seed legally fall, i.e., $\overline{\Pi}^{h}_{gm}$ drops to $\underline{\Pi}^{h}_{gm}$. With a small shift in $\overline{\Pi}^{h}_{gm}$ to $\underline{\Pi}^{h}_{gm}$, i.e., with a 'low' tax, the total quantity of GM seed usage drops from $(x^{c}_{gm} + x^{h}_{gm})$ to $(\underline{x}^{c}_{gm} + \underline{x}^{h}_{gm})$, increasing the traditional seed purchases from x_t to $\underline{x}_t$. Thus, in the post-tax scenario, the total GM seed usage (both legal and illegal) is given by $A^{(new)}_{gm}$ which is derived by equating Π_t and $\underline{\Pi}^{h}_{gm}$ as follows

$$A^{(new)}_{gm} = \frac{p_{gm} - p_t + p^{s}_{t} - (\breve{p}^{s}_{gm} + \tau_1)}{\gamma - \phi} \qquad (3.47).$$

Subtracting $A^{(new)}_{gm}$ from A_{gm} (shown in equation 3.25), and substituting the values of $\overline{p}^{s}_{gm}$ and $\breve{p}^{s}_{gm}$ from the innovator's problems, one gets $A_{gm} - A^{(new)}_{gm} = \dfrac{\tau_1}{2(\gamma - \phi)} > 0$.

Thus, the total GM seed usage with tax, $A^{(new)}_{gm}$, is less than that without the tax.

Additionally, in the process the quantity of GM seed acquired illegally increases from x^{c}_{gm} to $\underline{x}^{c}_{gm}$. The revised quantity of GM crop produced with illegally acquired seed is given by

$$A^{c(new)}_{gm} = \frac{(\breve{p}^{s}_{gm} + \tau_1) - m}{\delta_0 \rho} \qquad (3.48).$$

The value $A^{c(new)}_{gm}$ is higher in absolute magnitude than that produced in the pre-tax scenario, given by A^{c}_{gm} (equation 3.24). This can be verified by subtracting A^{c}_{gm} from $A^{c(new)}_{gm}$, i.e., $A^{c(new)}_{gm} - A^{c}_{gm} = \dfrac{\tau_1}{2\delta_0 \rho} > 0$, thus completing the proof.

Thus the critical level of tax turns out to be $\tau_f = \dfrac{(p_t^s - p_t + p_{gm} - m)\delta_0\rho}{\gamma - \phi + \delta_0\rho} + m - \breve{p}_{gm}^s$, or substituting the value of $\breve{p}_{gm}^s$ from the innovator's problem, $\tau_f = \dfrac{(p_t^s - p_t + p_{gm} - m)\delta_0\rho}{\gamma - \phi + \delta_0\rho}$. This points toward the simple intuition that if the tax rate is such that the monopolist is compelled to set the legal GM seed price equal to the constant marginal cost, i.e., $\breve{p}_{gm}^s = m$, then the monopolist will be driven out of the market, and therefore, the quantity of legal GM seed exchanged would be $\underline{x}_{gm}^h = 0$. Hence, a 'low' tax should imply $\tau_1 < \tau_f = \dfrac{(p_t^s - p_t + p_{gm} - m)\delta_0\rho}{\gamma - \phi + \delta_0\rho}$. Thus, due to the imposition of a 'low' level of tax (τ_1), a 'small' parallel shift occurs in the net returns function associated with legal GM crop from $\overline{\Pi}_{gm}^h$ to $\underline{\Pi}_{gm}^h$, so that both of those curves remain above the critical point '*f*'. This causes the quantity of GM seed usage to decrease; in particular, it reduces the use of legal GM seed but causes illegal GM seed usage to increase.

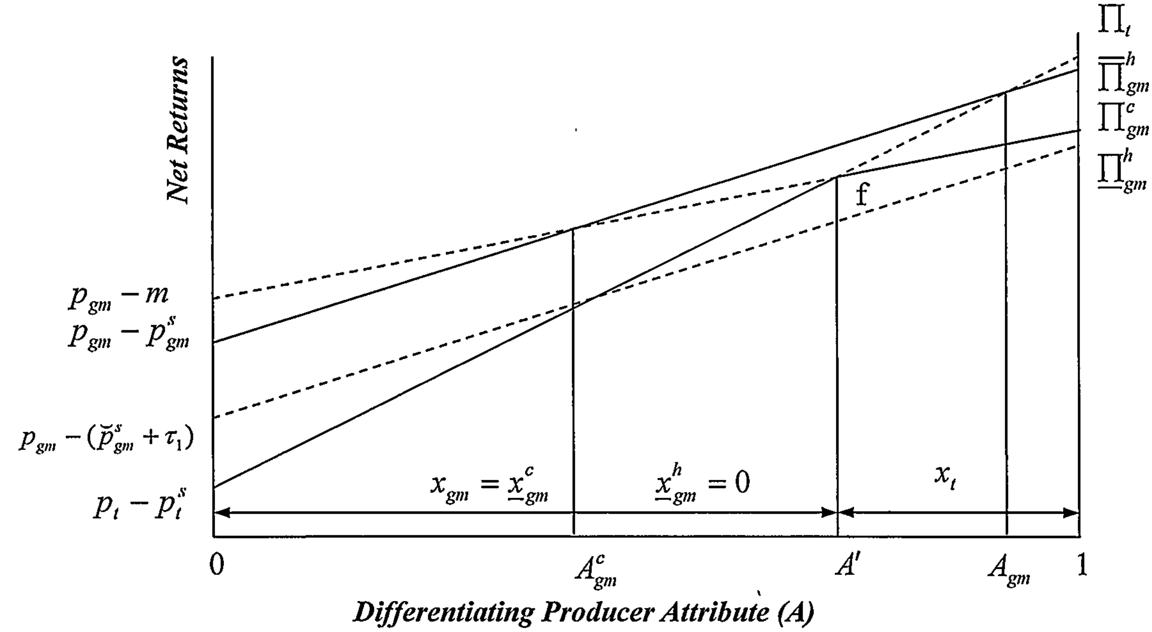

Figure 3.10: Producer's net returns under imperfect IPR enforcement with 'high' tax

Proposition 4: A 'high' level of corrective tax on legally acquired GM seeds reduces total GM seed usage and causes the legal GM seed component to disappear completely.

Proof: This scenario occurs when the rate of tax is such that $\tau_1 > \dfrac{(p_t^s - p_t + p_{gm} - m)\delta_0 \rho}{\gamma - \phi + \delta_0 \rho}$ implying $\underline{\Pi}_{gm}^h$ is at or below point '*f*' in the post-tax situation, as shown in Figure 3.10. When producers are taxed for buying a unit of legal GM seed, $\overline{\Pi}_{gm}^h$ drops to $\underline{\Pi}_{gm}^h$. However, in this case, the level of tax is so 'high' that the net returns function associated with legal GM output falls below the critical point '*f*', leading to zero legal GM seed usage in the post-tax situation. Following Proposition 1, it means that all the producers find the expected penalty, if caught, to be lower than the tax-inclusive price of GM seed. In this case, the total GM seed usage is given by A', which is illegally acquired. That is,

$$A' = \frac{p_{gm} - p_t + p_t^s - m}{\gamma - \phi + \delta_0 \rho} = \frac{B - m}{\gamma - \phi + \delta_0 \rho} \qquad (3.49)$$

, which is derived by equating Π_t to Π_{gm}^c, from equations (3.1) and (3.22*A*) respectively. The value A' is same as A_f in (3.36) as both represent the critical level of producers' attribute.

In the post-tax scenario, total GM seed usage, A' is lower than that in the pre-tax scenario, given by A_{gm}, but higher than the pre-tax illegal GM seed component, A_{gm}^c. Thus, relative to a 'low' tax rate, imposition of a 'high' tax (τ_1) causes a larger shift in the producers' net returns function associated with legal GM output, so that $\underline{\Pi}_{gm}^h$ lies below the critical point '*f*' and the legal GM seed component disappears completely. The only GM output existing is the illegal component.

Comparing propositions 3 and 4, it can be observed that if the tax rate were to be too high, the effect would be to eliminate all legal GM seed sales. Under such circumstance, the foreign innovator would choose to exit the domestic market. In some cases, it could be true that $\underline{x}_{gm}^{h} = 0$ is welfare maximizing. Either of the cases, namely, 'low' or 'high' tax could be possible. For the present analysis, the rather interesting case is that of a 'low' tax where all three categories of GM seeds are used.

Proposition 5: Provided that demand is linear and that marginal costs are constant, the static incidence of the tax is shared equally by the domestic producer and the foreign innovator, i.e., each suffer an equal loss in returns per unit of legal GM seed bought or sold in the new equilibrium. (It is to be noted that the innovator's loss in total surplus is given by the 'L' shaped hatched area in Figure 3.10., which is not fully captured by the incidence of tax and which is not shared equally with producers.)

Proof: Figure 3.9 helps understand this issue. The part of the incidence of tax which is borne by the innovator is shown by the hatched area and is given by $(\overline{p}_{gm}^{s} - \breve{p}_{gm}^{s}) \times \underline{x}_{gm}^{h}$.

From equation (3.26), $\overline{p}_{gm}^{s} = \dfrac{\delta_0 \rho (p_{gm} - p_t + p_t^s) + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0 \rho)} + \dfrac{m}{2} = \dfrac{\delta_0 \rho B + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0 \rho)} + \dfrac{m}{2}$,

and from equation (3.37),

$\breve{p}_{gm}^{s} = \dfrac{\delta_0 \rho (p_{gm} - p_t + p_t^s) + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0 \rho)} - \dfrac{\tau_1 - m}{2} = \dfrac{\delta_0 \rho B + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0 \rho)} - \dfrac{\tau_1 - m}{2}$. Thus, substituting equations (3.26) and (3.37) into the expression for tax incidence shown above, the tax burden of the innovator is $\dfrac{\tau_1}{2} \times \underline{x}_{gm}^{h}$. Similarly, the part of the tax incidence borne by the domestic producers is calculated at $(\underline{p}_{gm}^{s} - \overline{p}_{gm}^{s}) \times \underline{x}_{gm}^{h}$. From equation (3.38), $\underline{p}_{gm}^{s} = \dfrac{\delta_0 \rho (p_{gm} - p_t + p_t^s) + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0 \rho)} + \dfrac{\tau_1 + m}{2}$. Therefore, the tax burden of the domestic producers simplifies to $\dfrac{\tau_1}{2} \times \underline{x}_{gm}^{h}$. Thus, in this case, with linear demand and constant marginal cost faced by the innovator, the tax burden per unit to both the agents is equal. It is useful to mention that an upward sloping marginal cost will lead to different equilibrium values and therefore, different proportions of tax burden to be shared between the two entities.

3.3 Subsidy as a policy instrument under the perfect enforcement of intellectual property rights in the developing country

In this section, case (iv) of Table 3.1 is described. In response to the negative externalities caused due to the production of genetically modified crops, the government in the developing country can levy a corrective subsidy per unit of traditional seed purchased, as an alternative to the corrective tax discussed in the earlier sections.[2] One should be able to compare the two policy tools, in terms of the resultant producers' surplus, innovator's rent and other components of overall social welfare.

3.3.1 Case (iv): Negative externalities occur, corrective subsidy levied per unit of traditional seed purchased as a policy measure

Here, the domestic government introduces subsidy η_0 per unit of traditional seed purchased under the perfect enforcement scenario. Thus the government expects to encourage traditional crop production and in the process, reduce the quantity of GM crop. As before, the suppliers of traditional seed face a competitive market. Further, assuming the subsidy is paid to the suppliers of traditional seed, the price of seed drops to $(p_t^s - \eta_0)$ from p_t^s. The producers' net returns function for traditional crop alters from (3.1) to

$$\overline{\overline{\Pi}}_t = p_t - (p_t^s - \eta_0) + \gamma A \qquad (3.50).$$

[2] A subsidy might alternatively be offered in the market for GM seed, such as by providing a per unit subsidy to producers for each unit reduction in use of GM seed, x_{gm}^s as measured from the benchmark scenario of case (i). The effects of a subsidy in that market are expected to parallel closely the effects of the corrective tax in case (iii), and are not modeled formally here.

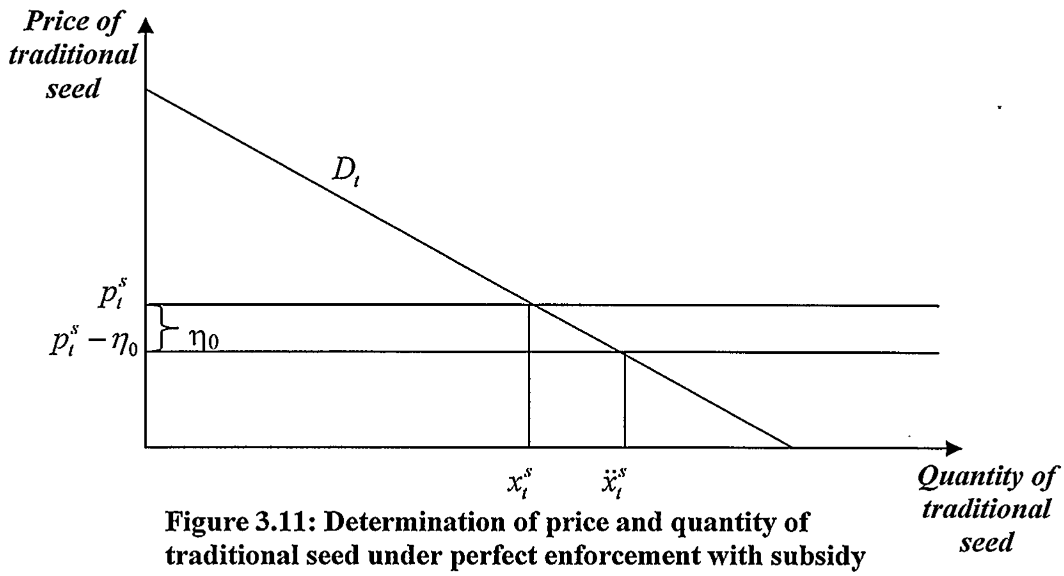

Figure 3.11: Determination of price and quantity of traditional seed under perfect enforcement with subsidy

Determination of price and quantity of traditional seed is shown graphically in Figure 3.11. Since the market is characterized by perfect competition, output is quantity demanded at the subsidized price. In the pre-subsidy scenario, price charged by the seed suppliers is p_t^s and the quantity of traditional seed purchased is x_t^s. When the price of traditional seed drops to $(p_t^s - \eta_0)$ due to the introduction of the subsidy, quantity demanded increases to $\ddot{x}_t^s$.

The subsidy could instead be paid to the producers of traditional crop, who are also the buyers of traditional seed. In that case, equation (3.50) would remain the same, only the graphical representation in Figure 3.11 would change a little. When the subsidy η_0 is paid to the producers of traditional crop, the demand for traditional seed increases, shifting the demand schedule D_t parallel and upward by the amount of the subsidy. This in turn increases the quantity exchanged of traditional seed from x_t^s to $\ddot{x}_t^s$ and ensures that seed suppliers receive p_t^s as before.

A decrease in the domestic price of traditional seed has a repercussion in the GM seed market in the developing country, namely, a fall in demand for GM seed. The loss in demand experienced by the innovator would be exactly equal to the amount of the

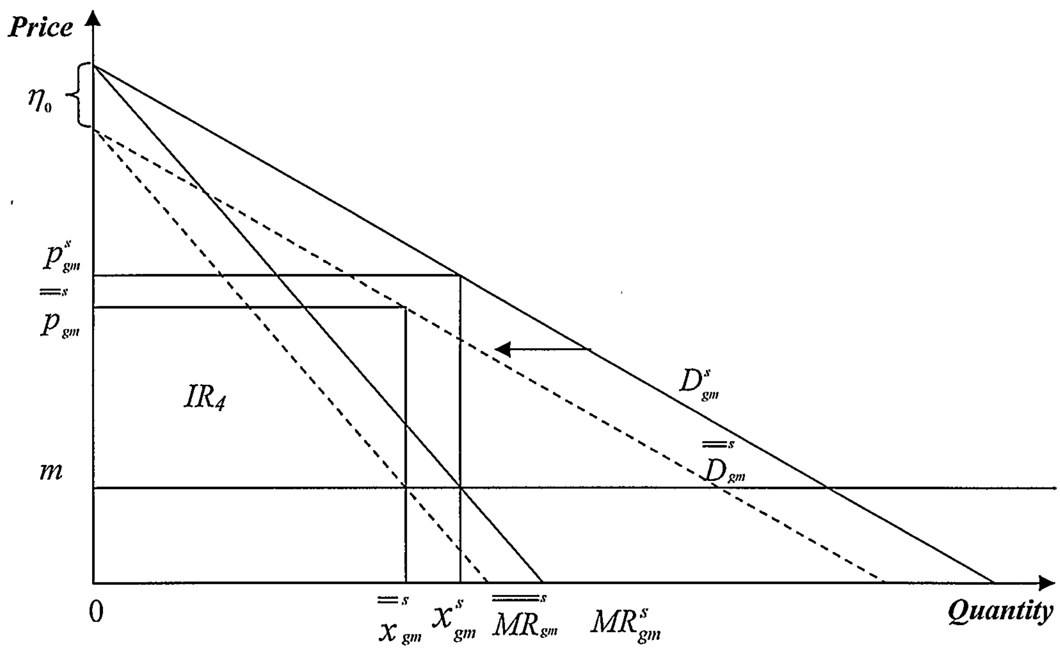

Figure 3.12: Innovator's price and quantity revision in response to change in the price of traditional seed as a result of per unit subsidy

subsidy, η_0. This will be easier to follow when the innovator's problem is solved. Consequently, the innovator would revise the equilibrium price and quantity of GM seed. This can be observed in Figure 3.12.

Demand and marginal revenue curves faced by the innovator were D^s_{gm} and MR^s_{gm} respectively, before the subsidy and p^s_{gm} and x^s_{gm} were the resultant price – quantity combination in that scenario. A decrease in the domestic price of traditional seed is reflected in the figure in the form of a parallel inward shift in the monopolist's demand curve. The new demand and marginal revenue curves are $\overline{\overline{D}}^s_{gm}$ and $\overline{\overline{MR}}^s_{gm}$, and the revised equilibrium price and quantity in the subsidy scenario are $\overline{\overline{p}}^s_{gm}$ and $\overline{\overline{x}}^s_{gm}$ respectively. Therefore, when the innovator adjusts to the introduction of a subsidy in the other seed market, the producers' net returns function for the legal GM crop variety can be re-written as

$\overline{\overline{\Pi}}{}^{h}_{gm} = p_{gm} - \overline{\overline{p}}{}^{s}_{gm} + \phi A \qquad (3.51).$

In response to the revision of equilibrium price-quantity combination by the innovator, demand for traditional seed falls, until the quantity $\overline{\overline{x}}{}^{s}_{t} = (1 - \overline{\overline{x}}{}^{s}_{gm})$ is reached, $x_t^s < \overline{\overline{x}}{}^{s}_{t} < \ddot{x}_t^s$. Note that the fixed, total quantity of seeds (traditional as well as GM) is normalized to 1, so that the total quantity of seed usage should always equal to 1 after all adjustments. The equilibrium price for traditional seed remains fixed at $(p_t^s - \eta_0)$. This is illustrated in Figure A in Section 3.3(A) of Appendix A. Comparing the equilibria without and with the subsidy, respectively, the quantity exchanged of traditional seed has increased, of GM seed has decreased, and their relative market shares still sum to 100 percent.

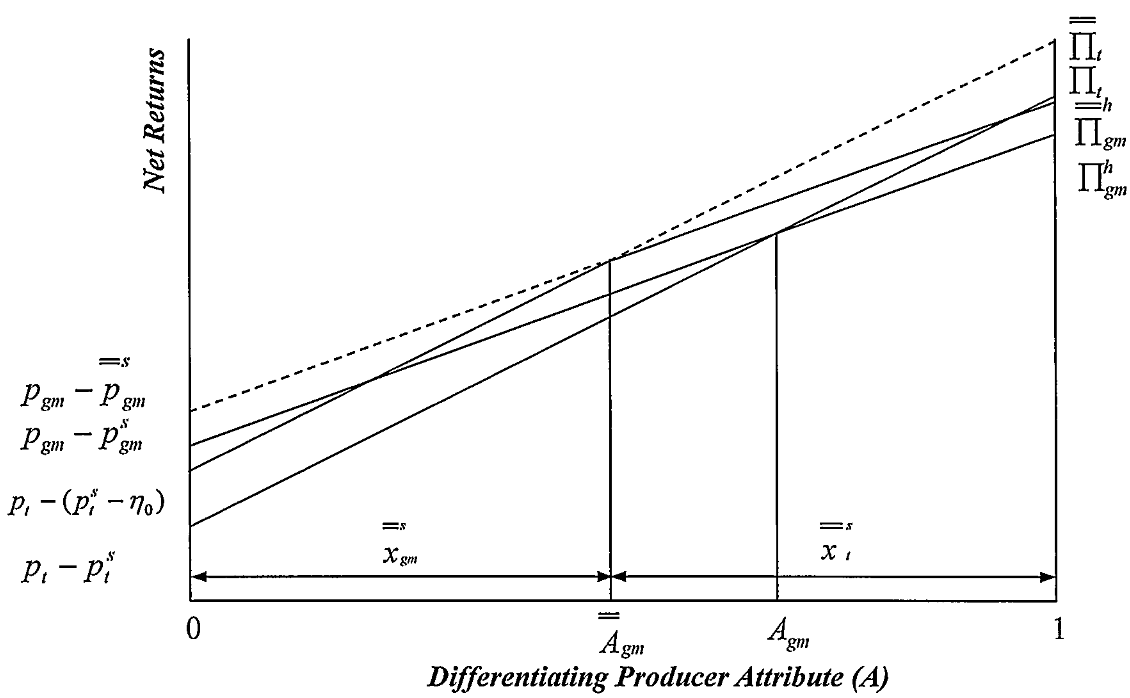

Figure 3.13: Producer's net returns under perfect enforcement with per unit subsidy

Producers' net returns functions from various crops are shown in Figure 3.13. As a result of the effects described above, namely, the fall in the price of traditional seed as well as that of GM seed in the domestic market, producers' net returns associated with both types of crops increase. In Figure 3.13, net returns from the traditional crop, Π_t go up to $\overline{\overline{\Pi}}_t$ and the net returns from GM crop production, Π^h_{gm} increase to $\overline{\overline{\Pi}}^h_{gm}$. The changes are easier to see when a comparison is drawn between Figure 3.2 presented earlier describing case (i) and Figure 3.13 presented here. Due to the introduction of the subsidy, at rate η_0, the current level of GM crop production reduces from A_{gm} to $\overline{\overline{A}}_{gm}$, which is given by

$$\overline{\overline{A}}_{gm} = \frac{(p_{gm} - \overline{\overline{p}}^s_{gm}) - (p_t - p^s_t) - \eta_0}{\gamma - \phi} \qquad (3.52).$$

The innovator, in the second stage of the sequential game determines the price of the GM seed by maximizing its profit. The innovator's objective can be presented as

$$\max_{\overline{\overline{p}}^s_{gm}} \pi = (\overline{\overline{p}}^s_{gm} - m)\overline{\overline{x}}^s_{gm}.$$

Solving the above problem (derivations are presented in Section 3.3(B) of Appendix A), the equilibrium price of GM seed is given by

$$\overline{\overline{p}}^s_{gm} = \frac{p_{gm} - p_t + p^s_t - \eta_0 + m}{2} \qquad (3.53),$$

and the equilibrium quantity of GM seed is

$$\overline{\overline{x}}^s_{gm} = \frac{p_{gm} - p_t + p^s_t - \eta_0 - m}{2(\gamma - \phi)} \qquad (3.54).$$

Figure 3.12 presented earlier shows the determination of the equilibrium price and quantity by the foreign innovator under the subsidy. Since the innovator is a monopolist in the domestic market, the equilibrium quantity is determined by the intersection of the marginal revenue $\overline{\overline{MR}}^s_{gm}$ and the constant marginal cost m.

At the last stage of backward induction, the government's objective as a social planner is to maximize social welfare (W_4) which consists of producers' surplus (PS_4), minus externalities (D_4^{PE}), minus the subsidy payment made to the traditional seed suppliers (Pa_4), where the government's choice variable is the level of subsidy, η_0. The problem can be formally stated as

$$\max_{\eta_0} W_4 = PS_4 - D_4^{PE} - Pa_4,$$
$$subject\ to\ \ IR_4 > r_4\ \ (\geq 0).$$

Producers' surplus is determined by the area below the dotted lines in Figure 3.13 (derivation is presented in Section 3.3(C) of Appendix A).

$$PS_4 = \int_0^{\bar{A}_{gm}} \bar{\bar{\Pi}}_{gm}^{h} dA + \int_{\bar{A}_{gm}}^{1} \bar{\bar{\Pi}}_t dA = p_t - p_t^s + \frac{\gamma}{2} + \eta_0 + \frac{(B - m - \eta_0)^2}{8(\gamma - \phi)} \qquad (3.55).$$

The value of the negative external effects of new technology is

$$D_4^{PE} = c \times \bar{\bar{x}}_{gm}^{s} \qquad (3.56).$$

Total subsidy payments to the suppliers of traditional seed are

$$Pa_4 = \eta_0 \times (1 - \bar{\bar{x}}_{gm}^{s}) \qquad (3.57).$$

Examining Figure 3.12, innovator's rent in this case turns out to be

$$IR_4 = (\bar{\bar{p}}_{gm}^{s} - m) \times \bar{\bar{x}}_{gm}^{s} \qquad (3.58).$$

Solving the government's problem by using Kuhn–Tucker conditions, the optimal rate of subsidy (derivations are presented in Section 3.3(C) of Appendix A) is calculated to be

$$\eta_0^* = \frac{1}{3}(p_{gm} - p_t + p_t^s + 2c - m) \qquad (3.59).$$

Proposition 6: Under perfect enforcement of the IPRs, the absolute magnitudes of optimum tax per unit of GM seed and of optimal subsidy per unit of traditional seed are equal.

Proof: Comparing equations (3.21) and (3.59) of the perfect enforcement scenario under tax and subsidy regimes respectively, it is observed that the absolute magnitudes of the optimal levels of the two policy instruments are equal, i.e., $\tau_0^* = \eta_0^* = \frac{1}{3}(p_{gm} - p_t + p_t^s + 2c - m)$. It should be noted, however, that the "bases" to which these taxes and subsidies apply, are quite different but related. Specifically, the tax τ_0^* is applied to increase the price of the GM seeds across that crop's market share, whereas the subsidy is applied to reduce the price of the traditional seeds across that crop's market share. Since the two shares sum to unity and are in that sense complements, either instrument applied at this uniform rate has the same effect on the monopolist's output level as will be seen, on total social welfare. The effect of the two instruments on various components of social welfare may be quite different, however.

3.4 Subsidy as a policy instrument under the imperfect enforcement of intellectual property rights in the developing country

In this section, case (viii) of Table 3.2 is discussed. This is the case of less than perfect enforcement of the innovator's rights in the developing country, i.e., the case when there is potential for producing genetically modified crops illegally, without paying for the price of the GM seed. Here, subsidy is considered as a policy instrument adopted by the developing country government to counter the negative externalities.

3.4.1 Case (viii): Negative externalities occur, corrective subsidy levied per unit of traditional seed purchased as a policy measure

In the method of backward induction, the producers' problem is considered first. Assuming government levies a subsidy η_1 per unit of traditional seed purchased, price of traditional seed drops from p_t^s to $(p_t^s - \eta_1)$. Denoting producer's net returns from the production of traditional crop as Π_t'',

$$\Pi_t'' = p_t - (p_t^s - \eta_1) + \gamma A \qquad (3.60).$$

As is explained under perfect enforcement scenario, as a result of subsidizing the traditional seed suppliers, the price of seed drops and quantity demanded increases. In response to this, willingness to pay for GM seed falls. Therefore, price of GM seed drops in the developing country market. Let $p_{gm}''^{s}$ be the revised price of GM seed and $x_{gm}''^{h}$ be the quantity of GM seed supplied by the innovator. Denoting producer's net returns from the production of legal GM crop as $\Pi_{gm}''^{h}$,

$$\Pi_{gm}''^{h} = p_{gm} - p_{gm}''^{s} + \phi A \qquad (3.61).$$

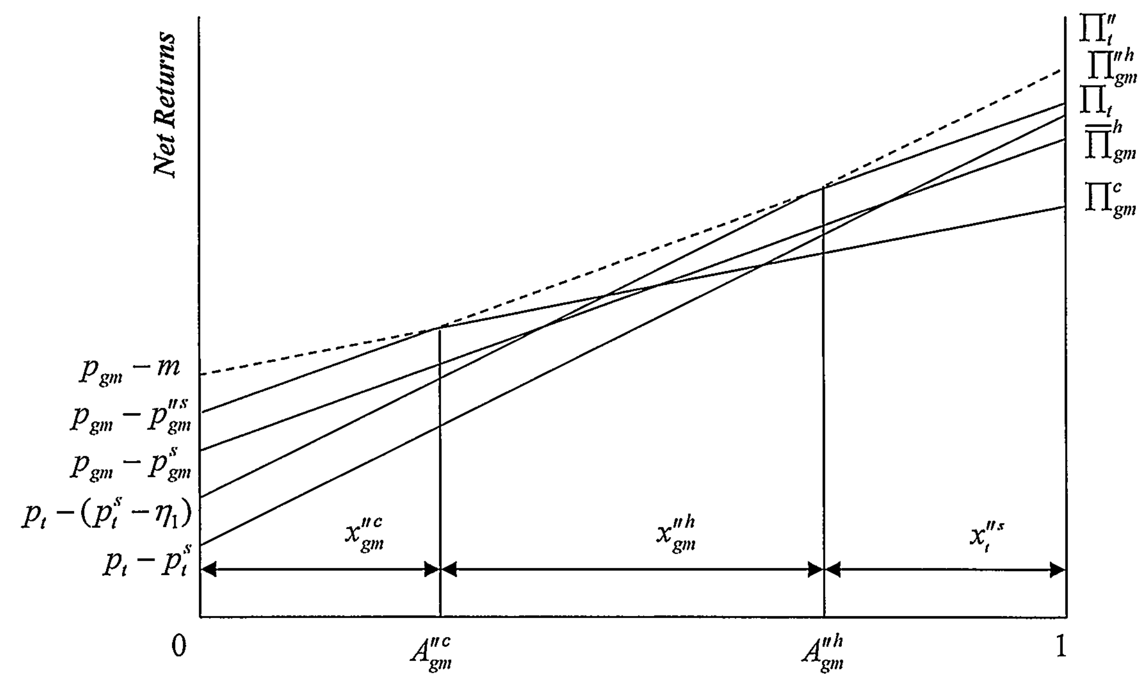

Figure 3.14: Producers' net returns under imperfect enforcement of IPRs with a corrective per unit subsidy

As the price of the GM seed falls, the willingness to pay for traditional seed drops slightly until the equilibrium quantity $x_t''^s$ is reached, such that, $x_t''^s$ equals $(1-(x_{gm}''^h + x_{gm}''^c))$. The net effect of the subsidy is to reduce total GM crop production, reduce the quantity of illegally acquired GM seeds and increase the production of traditional crop output. The net returns function from illegally produced GM output is given by

$$\prod_{gm}^c = p_{gm} + \phi A - \delta_0 \rho A - m \qquad (3.22A).$$

Figure 3.14 shows various net returns functions of the producers. As a result of subsidizing traditional seed, the cost of traditional crop production falls, therefore, the net returns earned by the producers from traditional crop increases. This is shown by the parallel shift of $\prod_t$ to $\prod''_t$. This affects the foreign innovator adversely as the demand for GM seed falls. The innovator responds by reducing the price of GM seed, thus, the net returns obtained by the domestic producers from legal GM crop production increase as well. This is shown by the parallel upward shift of $\overline{\prod}_{gm}^h$ to $\prod''^h_{gm}$. New levels of GM and traditional seed usage are $x_{gm}''^h$ (legal), $x_{gm}''^c$ (illegal) and $x_t''^s$ respectively. Comparing Figure 3.14 with Figure 3.7 above, it is observed that the differentiating producers' attribute A_{gm} that corresponds to total GM crop production under imperfect enforcement without any policy instruments, shifts to the left to $A_{gm}''^h$ under the subsidy regime. This implies that subsidy, as a government policy to internalize the externalities, reduces total GM crop production. On the other hand, comparing the two figures, it is revealed that the differentiating producers' attribute A_{gm}^c that corresponds to the GM crop production using illegally acquired seeds under imperfect enforcement without any policy instruments, also shifts to the left to $A_{gm}''^c$ under the subsidy regime.

Producer characteristics $A_{gm}''^c$ and $A_{gm}''^h$ are given by

$$A''^{c}_{gm} = \frac{p''^{s}_{gm} - m}{\delta_0 \rho}$$ (3.62), which is derived by equating Π^{c}_{gm} to Π''^{h}_{gm}, and

$$A''^{h}_{gm} = \frac{B - \eta_1 - p''^{s}_{gm}}{\gamma - \phi}$$ (3.63), which is derived by equating Π''_{t} to Π''^{h}_{gm}.

The foreign innovator maximizes profits by determining the optimal price of the GM seeds. The innovator's problem can be presented as

$$\max_{p''^{s}_{gm}} \pi = (p''^{s}_{gm} - m)x''^{h}_{gm}.$$

Solving the innovator's problem (derivations presented in Section 3.4(A) of Appendix A) the following equilibrium price is obtained:

$$p''^{s}_{gm} = \frac{(p_{gm} - p_t + p^{s}_{t} - \eta_1)\delta_0 \rho + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0 \rho)} + \frac{m}{2} \qquad (3.64).$$

Substituting p''^{s}_{gm} from equation (3.64) into the producers' attribute A''^{c}_{gm} given by equation (3.62) and A''^{h}_{gm} given by equation (3.63), the quantity of GM seeds purchased legally is obtained as

$$x''^{h}_{gm} = \frac{(p_{gm} - p_t + p^{s}_{t} - \eta_1 - m))}{2(\gamma - \phi)} \qquad (3.65).$$

Similarly, substituting p''^{s}_{gm} from equation (3.64) into the producers' attribute A''^{c}_{gm} given by equation (3.62) above, the quantity of GM seed acquired illegally is obtained as

$$x''^{c}_{gm} = A''^{c}_{gm} = \frac{(p_{gm} - p_t + p^{s}_{t} - \eta_1 - m)}{2(\gamma - \phi + \delta_0 \rho)} \qquad (3.66).$$

Figure 3.15 shows the determination of the innovator's price and quantity of GM seed in the monopolistic market faced by the innovator. The pre-subsidy willingness to pay for the seed reduces as a result of the subsidy, shown by the inward shift of the demand curve from D^{s}_{gm} to D''^{s}_{gm}. When the monopolist chooses the new profit maximizing post-subsidy price, p''^{s}_{gm} and quantity, x''^{s}_{gm}, the innovator's rent decreases by the 'L' shaped hatched area in the figure

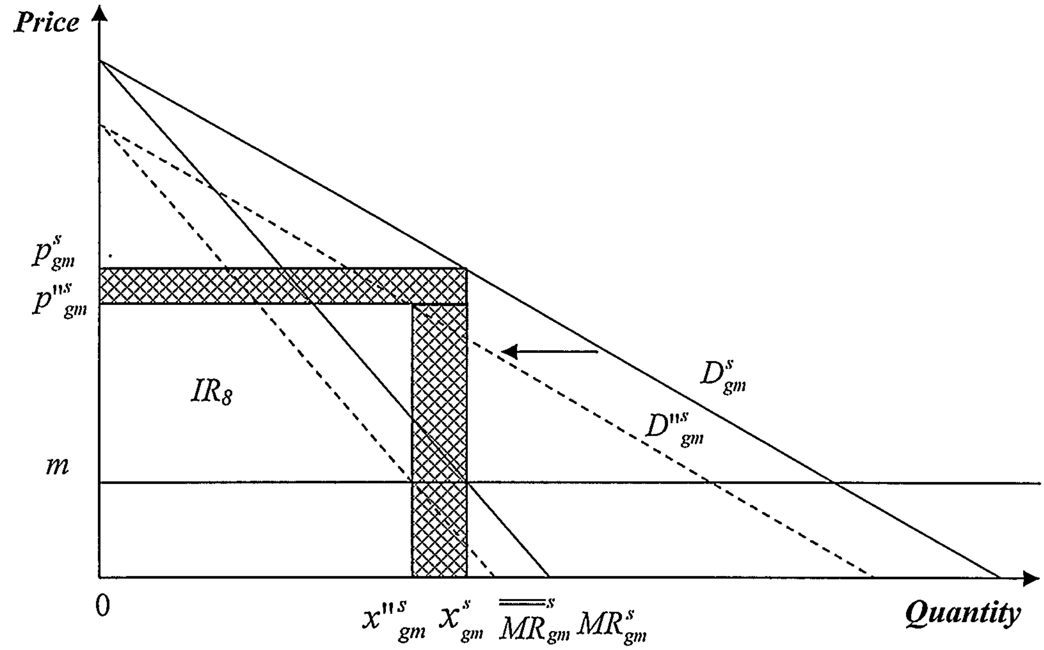

Figure 3.15: Innovator's price and quantity revision in response to change in the price of traditional seed as a result of per unit subsidy under imperfect enforcement of IPRs

Finally, the government's objective as a social planner is to maximize social welfare by the choice of the optimal level of subsidy, η_1, to be levied. Social welfare (W_8) consists of producer surplus (PS_8), minus enforcement costs (EC), minus external effects (D_8^{IE}), minus subsidy payment (Pa_8) plus expected revenue earned through expected penalty (F_8). Formally, government's problem can be written as

$$\max_{\tau_0} W_8 = PS_8 - EC - D_8^{IE} - Pa_8 + F_8,$$
$$\textit{subject to} \quad IR_8 > r_8 \ (\geq 0).$$

Producer surplus is the area below the dotted lines in Figure 3.14 (derivation is presented in Section 3.4 (B) of Appendix A)

$$PS_8 = \int_0^{A''^{c}_{gm}} \Pi^c_{gm} dA + \int_{A''^{c}_{gm}}^{A''^{h}_{gm}} \Pi''^{h}_{gm} dA + \int_{A''^{h}_{gm}}^{1} \Pi''_t dA$$
$$= p_t - p_t^s + \frac{\gamma}{2} + \eta_1 + \frac{(-B + m + \eta_1)^2}{8(\gamma - \phi)} + \frac{3(-B + m + \eta_1)^2}{8(\gamma - \phi + \delta_0 \rho)} \qquad (3.67).$$

Enforcement cost of the IPRs is given by

$$EC = \alpha\delta_0 + \beta > 0 \qquad (3.68).$$

Negative externalities are associated with both legal and illegal GM seed components,

$$D_8^{IE} = c \times (x''^{h}_{gm} + x''^{c}_{gm}) > 0 \qquad (3.69).$$

Total subsidy payment depends on the total non-GM seed usage,

$$Pa_8 = \eta_1[1 - (x''^{h}_{gm} + x''^{c}_{gm})] > 0 \qquad (3.70).$$

Expected public revenue from the penalty, F_7, can be thought of as a function of the producers' probability of getting caught while cheating ($\delta_0 A$) and the penalty (ρ),

$$F_8 = \rho \int_0^{A''^{c}_{gm}} (\delta_0 A) dA \qquad (3.71).$$

The innovator's rent (IR_8) in this case is given by

$$IR_8 = (p''^{s}_{gm} - m) \times x''^{s}_{gm} \qquad (3.72).$$

Solving the government's problem using a Lagrange multiplier (derivations are presented in Section 3.4 (B) of Appendix A) the optimal rate of subsidy turns out to be

$$\eta_1^* = c + (B - c - m)\left[\frac{\delta_0^2 \rho^2}{4\gamma^2 + 6\gamma\delta_0\rho + 3\delta_0^2\rho^2 - 8\gamma\phi - 6\phi\delta_0\rho + 4\phi^2}\right] \qquad (3.73).$$

***Proposition** 7:* A corrective subsidy per unit of traditional seeds as a government policy reduces the total quantity of GM seeds purchased and that of illegally acquired GM seeds.

Proof: Comparing the producers' attribute corresponding to the total GM seed usage under imperfect enforcement without any policy instruments, i.e., equation (3.25) in case (v) $A_{gm} = \dfrac{p_{gm} - p_t + p_t^s - \overline{p}^{s}_{gm}}{\gamma - \phi}$, with that under imperfect enforcement with subsidy, i.e., equation (3.63) in case (viii), $A''^{h}_{gm} = \dfrac{B-\eta_1 - p''^{s}_{gm}}{\gamma-\phi}$, and substituting $\overline{p}^{s}_{gm}$ from equation (3.26) and p''^{s}_{gm} from equation (3.64), it is observed that $A_{gm} - A''^{h}_{gm} = \dfrac{(\gamma-\phi)\eta_1}{2(\gamma-\phi+\delta_0\rho)(\gamma-\phi)} > 0$. Thus, the quantity of total GM seed usage falls due to the introduction of a subsidy as a government policy. Similarly, comparing the producers' attribute corresponding to the illegally acquired GM seed usage under imperfect enforcement without any policy instruments, i.e., equation (3.24) in case (v) $A^{c}_{gm} = \dfrac{\overline{p}^{s}_{gm} - m}{\delta_0\rho}$, with that under imperfect enforcement with subsidy, i.e., equation (3.62) in case (viii), $A''^{c}_{gm} = \dfrac{p''^{s}_{gm} - m}{\delta_0\rho}$, and substituting $\overline{p}^{s}_{gm}$ from equation (3.26) and p''^{s}_{gm} from equation (3.64), it is observed that $A^{c}_{gm} - A''^{c}_{gm} = \dfrac{\eta_1}{2(\gamma-\phi+\delta_0\rho)} > 0$. Thus, the quantity of illegally acquired GM seed usage falls due to the introduction of a subsidy as a government policy.

3.5 Summary and Conclusions

In this chapter, government policy tools have been proposed to address the negative externalities arising from the cultivation of genetically modified crops in a developing country. In particular, two separate models have been developed – one includes tax as a government policy and the other considers subsidy as an alternative policy instrument. In both cases, optimal policy tools have been designed so as to maximize social welfare. In the next chapter, numerical simulations are carried out to illustrate the results of analytical models.

CHAPTER FOUR: DISCUSSION OF ANALYTICAL RESULTS AND NUMERICAL ANALYSIS

This chapter presents a discussion of the assumptions, methodology and the results of the model. In particular, the assumptions which are specific to the current model, and therefore different from Giannakas (2002), are analyzed in detail. In addition, the outcomes of various cases under the two regimes of IPR enforcement are discussed and the associated social welfare levels are compared. As well, the analytical results obtained in the previous chapter are illustrated using numerical simulations.

In the next section (section 4.1) a comparison is drawn between the equilibria achieved under 'with' and 'without' government policy regimes. Section 4.2 illustrates the analytical results derived in the last chapter by assigning values to the parameters of the model then using numerical simulations. Section 4.3 summarizes and concludes the chapter.

4.1 Comparative Study

In this section, a comparison is made between the tax per unit of GM seed purchased and subsidy per unit of traditional seed purchased as two policy measures the government may adopt in the face of negative externalities arising due to the production of crops using GM seeds. In particular, a comparison is drawn between the levels of social welfare and its various components achieved under the two policy regimes. There are some cases where comparison of analytical expressions provides uncertain results; use of numerical analysis seems useful in those cases.

A brief discussion is carried out of the assumptions made by Giannakas (2002) and those modified or developed in the present analysis. As already mentioned, case (i) in section 3.1 is a reproduction of Giannakas' (2002) results with slight modification on the assumption about the one-to-one correspondence between the GM seed usage and crop production. Specifically, in the present analysis, this one-to-one relation has been assumed away. Resultantly, the negative externality is linked directly to the GM seed usage and not to the output.

Similarly, in case (v), section 3.2, Giannakas' (2002) findings are discussed with the variation in the assumption on the parameter δ. Giannakas (2002) considered δ as a choice variable for the developing country government, implying that the government gets to choose the level of enforcement effort and the probability value of catching the producers who cheat. In other words, government determines the optimal level of enforcement of IPRs by choosing the optimal δ. In the current extension of Giannakas' (2002) work, it is assumed that the developing country government may not have a choice over δ as it depends on the economic condition of the country in question or is otherwise fixed in the short run time frame of the present analysis.

Intuitively, the probability (δ) of catching the producers who cheat under imperfect enforcement depends on the resources allocated towards enforcing IPRs, i.e., the enforcement costs (*EC*). The value of the enforcement cost determines how successful the government is in protecting the foreign innovator's rights. However, resource allocation varies from country to country depending on priorities set in terms of the government policies. Presumably, developing country governments aim their policies so as to solve more serious problems such as poverty and unemployment, whereas richer countries may have the opportunity to look beyond these primary aspects and focus on issues such as stronger IPR enforcement. Secondly, the value of δ might also depend upon the extent of corruption in the enforcement systems of the developing country. The producers who cheat can take advantage of the corruption among the enforcing agents, and avoid paying the penalty. Therefore, developing counties may be expected to have a lower δ compared to the developed countries, and compared to what is seen as the optimal level in developing countries in the absence of such corruption.

Another important issue to be considered at this point is the value of the parameter ρ, the penalty to be imposed on the producers if caught. In Giannakas (2002), the perfect enforcement of IPRs regime is denoted as the 'benchmark case' and an implicit assumption is made whereby the net returns function associated with cheating, $\prod^{c}_{gm}$, is zero. This implies that under perfect enforcement, no single producer finds cheating to yield higher net returns compared to that from the production of legal GM crop or traditional crop. However, in the current analysis, even under complete enforcement of the foreign innovator's rights, i.e., with δ = 1, any finite level of penalty ρ, results in at least some domestic producers who acquire GM seed illegally. These are the producers with the lowest levels of differentiating attribute (*A*). Clearly, to obtain a zero net return from illegally acquired GM seeds, the producers' attribute associated with illegal GM seed component must be zero. As for example, from equation (3.24) in section 3.2, for $A^{c}_{gm} = 0$, the level of penalty, ρ, should be set at infinity. Unless the penalty is *infinitely* high, which is a very limiting assumption, there is at least one producer who cheats, i.e., $A^{c}_{gm} > 0$. In the current discussion, this problem is avoided by assuming that, under perfect enforcement, the GM seed imported from the developed country is not replicable due to the presence of a terminator gene. Under imperfect enforcement, this assumption is not imposed.

Unlike Giannakas (2002), the present analysis considers a minimum cost of acquiring GM seeds illegally by the domestic producers, which is equivalent to the monopolist's marginal cost, *m*. Giannakas (2002) assumed it to be costless.

Table 4.1 summarizes the levels of welfare and its various components achieved with tax and subsidy under perfect enforcement of the IPRs. Under perfect enforcement, the aggregate welfare effects of the two policy instruments are equal, implying that both of the policy tools are equally efficient at reaching a given level of social welfare although its distribution varies considerably. Comparing the levels of producers' surplus realized

Components	Case (i): No externality	Case (iii): Tax	Case (iv): Subsidy
Price of GM seed	$\frac{p_{gm} - p_t + p_t^s + m}{2}$	$\frac{p_{gm} - p_t + p_t^s + m + \tau_0}{2}$	$\frac{p_{gm} - p_t + p_t^s - \eta_0 + m}{2}$
Quantity of GM seed	$\frac{p_{gm} - p_t + p_t^s - m}{2(\gamma - \phi)}$	$\frac{p_{gm} - p_t + p_t^s - m - \tau_0}{2(\gamma - \phi)}$	$\frac{p_{gm} - p_t + p_t^s - \eta_0 - m}{2(\gamma - \phi)}$
Optimal rate of tax or subsidy	NA	$\frac{1}{3}(p_{gm} - p_t + p_t^s + 2c - m)$	$\frac{1}{3}(p_{gm} - p_t + p_t^s + 2c - m)$
Producers' Surplus	$p_t - p_t^s + \frac{\gamma}{2} + \frac{(B-m)^2}{8(\gamma - \phi)}$	$p_t - p_t^s + \frac{\gamma}{2} + \frac{(c+m-B)^2}{18(\gamma - \phi)}$	$p_t - p_t^s + \frac{\gamma}{2} + \frac{(B+2c-m)}{3} + \frac{(c+m-B)^2}{18(\gamma - \phi)}$
Externality	NA	$\frac{c(B-m-c)}{3(\gamma - \phi)}$	$\frac{c(B-m-c)}{3(\gamma - \phi)}$
Tax Revenue	NA	$-\frac{(c+m-B)(B+2c-m)}{9(\gamma - \phi)}$	NA
Subsidy Payments	NA	NA	$\frac{(B+2c-m)(c+m-B+3(\gamma - \phi))}{9(\gamma - \phi)}$
Innovator's Rent	$\frac{(B-m)^2}{4(\gamma - \phi)}$	$\frac{(c+m-B)^2}{9(\gamma - \phi)}$	$\frac{(c+m-B)^2}{9(\gamma - \phi)}$
Social Welfare	$p_t - p_t^s + \frac{\gamma}{2} + \frac{(B-m)^2}{8(\gamma - \phi)}$	$p_t - p_t^s + \frac{\gamma}{2} + \frac{(c+m-B)^2}{6(\gamma - \phi)}$	$p_t - p_t^s + \frac{\gamma}{2} + \frac{(c+m-B)^2}{6(\gamma - \phi)}$

Table 4.1: Comparison of analytical results of various cases under perfect enforcement of IPR

Note: The constant $B = p_{gm} - p_t + p_t^s$.; NA: Not applicable under the two policy regimes, it is observed that the producers' surplus associated with subsidy, PS_4, is higher than that achieved with tax, PS_3, implying that the total net returns to the producers are higher under subsidy compared to tax. This can be verified from the changes in the levels of net returns derived from various seed usage after tax and subsidy under perfect enforcement. With the corrective tax, net returns from GM seed usage drops from $\prod_{gm}^{h}$, given by equation (3.2) to $\tilde{\prod}_{gm}^{h}$, given by equation (3.12) by the amount $\frac{\tau_0}{2}$. With the corrective subsidy, net returns from traditional seed increases from $\prod_t$, given by equation (3.1) to $\overline{\overline{\prod}}_t$, given by equation (3.50), by η_0 and net returns associated with the GM seed usage increases from $\prod_{gm}^{h}$, given by equation (3.2) to $\overline{\overline{\prod}}_{gm}^{h}$, given by equation (3.51), by $\frac{\eta_0}{2}$.

For the results presented in Table 4.1 to be true, following conditions must hold. First, as mentioned earlier, the constant c should be positive to imply negative external effects of agricultural biotechnology, i.e., $c \geq 0$. Secondly, producers' resistance to production risks and yield losses, as reflected in the production attributes, A, affects the crop returns through the parameters γ and ϕ, such that $\gamma > \phi > 0$. Thirdly, the price of GM seed charged by the monopolist should be greater than the marginal cost, m, as an example, in case (i) under perfect enforcement $p_{gm}^{s} > m$. Moreover, from figure 3.3, it can also be noted that the intercept of the monopolist's demand curve, B should be higher than either the price of GM seed or the marginal cost, i.e., $B > p_{gm}^{s} > m$.

The desirability of either of the policy tools is debatable from distributional aspect. Even though the two policy instruments seem to be equally efficient in terms of the levels of social welfare achieved, subsidy may be considered superior by some as it allocates higher surplus to the domestic producers. However, it may also be argued that the resources spent in subsidizing the suppliers of the traditional seed, who are also part of the land-owning class and therefore potentially well-off, might instead be used to feed or heal the poor, which is a more pressing problem in the developing country. Tax as a policy measure seems to be more efficient from the perspective of alternative distributional weights.

Close examination of Table 4.1 reveals that the monetary value of the negative externalities are equal under the two policy regimes and are given by $\frac{c(B-m-c)}{3(\gamma-\phi)}$. Similarly, the level of rent appropriated by the innovator under the policy regimes is also the same and is given by $\frac{(c+m-B)^2}{9(\gamma-\phi)}$. The innovator's rent with tax or subsidy is lower than that in case (ii) and is therefore lower than case (i), which is the benchmark case without any government policy in Giannakas (2002). This can also be verified from Figure 3.5, where the loss in the innovator's rent is shown by the 'L' shaped hatched area. This implies that the adoption of a policy measure on the part of the host government to counter the negative externality helps reducing repatriation of resources to the foreign innovator in the form of monopolist's rent.

The optimal tax or subsidy can raise host country welfare, yet, due to the presence of a foreign-owned monopoly, the "first best" outcome cannot be achieved by a single corrective instrument. The corrective tax or subsidy plays a dual role in addressing any negative externality and in capturing monopoly rents for the host country that would otherwise be repatriated. Numerical simulations presented in section 4.2, illustrate these and other key analytical results.

A comparison among the components of social welfare achieved under the two policy regimes can be made under the imperfect enforcement scenario. In case (vii), where a corrective tax under imperfect enforcement is introduced, it can be observed that as a result of introduction of the tax, the total GM seed purchases fall, but the proportion of illegally acquired seeds increase. In case (viii), on the other hand, where a corrective subsidy is levied, it is shown that both the total GM seed usage as well as the illegally acquired GM seed component decrease. These effects have important implications toward the levels of resultant social welfare. The level of social welfare achieved using the corrective tax is higher than that using the corrective subsidy. This is due to the fact that with tax, the quantity of illegally purchased GM seed increases implying that a higher fraction of domestic producers receive the benefits of the GM variety without the innovator repatriating the rents. This raises social welfare to the domestic country. On the other hand, with the corrective subsidy, the fraction of producers acquiring illegal GM seed drops. Thus, the foreign monopolist is able to capture higher profits in the form of economic rents. In this case, the domestic government foregoes part of the social welfare.

Due to the presence of many complex terms in the expressions of the imperfect enforcement regimes, in cases, it is difficult to draw unambiguous conclusions from the analytical expressions reported in chapter 3. These expressions are not tabulated or compared directly. The numerical analysis presented in section 4.2 below may be useful for this purpose

4.2 Numerical Analysis

In order to illustrate the analytical results obtained above, a numerical simulation is presented here. The parameters for the numerical model are chosen such that the net returns functions of the domestic producers show behavior similar to that described in the above analytical cases. As in the analytical modeling, the numerical model is developed using four stages, both for perfect and imperfect enforcement.

4.2.1 Policy decision under perfect enforcement scenario

Table 4.2 lists the parameters for the model used for the analysis. The values of the parameters are chosen in such a way that they schematically follow the behavior of the net returns functions of the producers. Table 4.3 presented at the end of this chapter summarizes the results obtained from various cases using numerical analysis. Figure 4.1 shows the net return functions of the producers under perfect enforcement of IPRs using the parameters presented in Table 4.2, in a scenario where there are no negative externalities and therefore no policy tools, i.e., case (i). Net returns associated with GM crop production using illegally acquired seed, Π^{c}_{gm}, is 'zero' in this scenario by definition. Assuming that there is one ton of seed that is used in total (to be consistent with the assumption of normalized quantity) and price of seed is measured in \$/ton, following equation (3.6), the price of GM seed is computed at \$2375/ton. It can be observed from the figure that the quantity of GM seed in this case is 0.69 tons, which satisfies equation (3.7) as well. In this benchmark case of Giannakas (2002), social welfare is only producers' surplus, which is calculated to be \$6901 according to equation (3.9).

Parameters	Values of the parameters
p_t	\$7000/ ton
p_t^s	\$5250 / ton
p_{gm}	\$6000/ ton
γ	\$9000/ ton
ϕ	\$6300/ ton
m	\$500/ ton
δ_0	0.4
ρ	\$13000/ ton
α	\$500
β	\$700
c	\$720/ ton

Table 4.2: Model parameters for numerical analysis

The intermediate case under perfect enforcement, namely, case (ii) in which externalities are detected, but no corrective measures are adopted by the government, differs from case (i) only in the value of social welfare. Figure 4.1 represents the net returns of the producers in case (ii) as well. Assuming the constant c in equation (3.10) to be \$720/ ton, the value of the negative externality arising from GM seed usage D_2^{PE}, in this case becomes \$500. The level of social welfare, given by equation (3.11), drops to \$6401 in this case. To be able to relate this numerical analysis with the analysis carried out in chapter 3, note that Figure 4.1 parallels Figure 3.2.

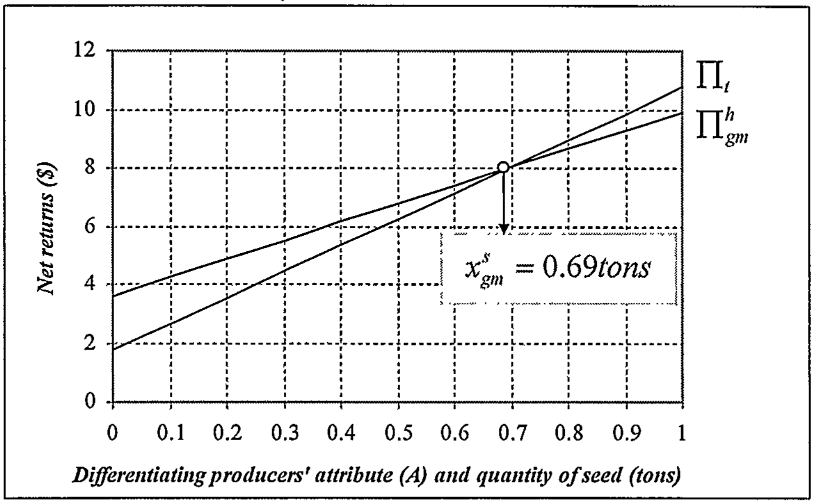

Figure 4.1: Illustration of cases (i) and (ii) under perfect enforcement using numerical analysis

In case (iii), the domestic government adopts a tax (τ_0) per unit of GM seed purchased as a policy measure in response to the negative externalities caused due to the usage of GM seed. In this case, the price of GM seed, inclusive of tax is given by equation (3.15) and

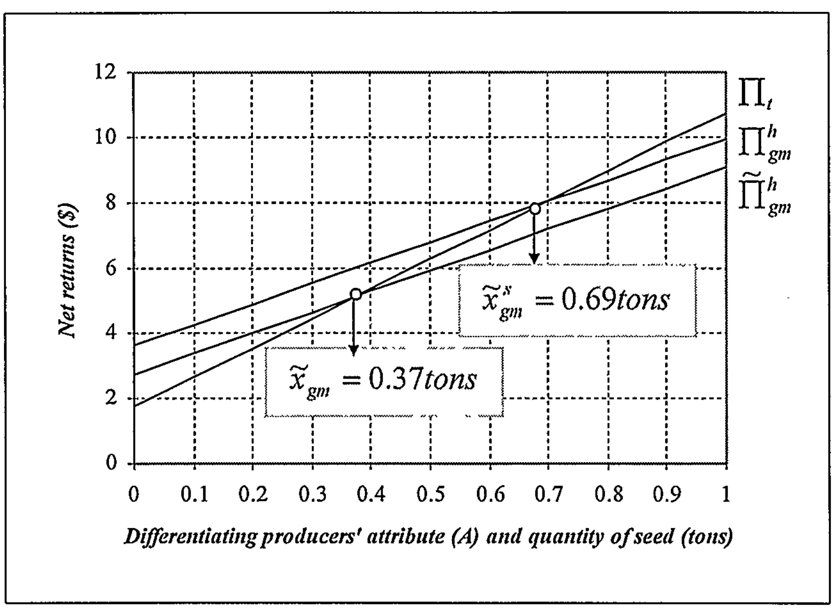

Figure 4.2: Illustration of case (iii) under perfect enforcement using numerical analysis

is calculated at \$3240/ton using the parameters in Table 4.2. Quantity of GM seed usage drops from 0.69 tons to 0.37 tons, which direction of change was expected in the analysis in chapter 3. Figure 4.2 shows the net return functions of the producers for this case. Figure 4.2 corresponds to Figure 3.4 in chapter 3. The optimal level of tax, solving government's problem turns out to be \$1730 per ton of GM seed usage. The value of social welfare in this case becomes \$6817, which is higher than in case (ii).

The last case to be considered under perfect enforcement is the one in which the domestic government as a policy tool levies a subsidy (η_0) per unit of traditional seed purchased towards internalizing the negative externalities. This has been described as case (iv) in section 3.3. In this case the optimal level of subsidy turns out to be equal to the optimal rate of tax, i.e., \$1730 per ton of traditional seed. As explained earlier, the drop in the price of traditional seed due to subsidy leads to a reduction in the price of GM seed by the innovator. Therefore, producer's surplus from both traditional crop and legal GM crop increases. The value of producer's surplus in this case turns out to be \$8169, which is higher than that achieved with the tax, \$6439. The price of GM seed after the subsidy is calculated at \$1510/ ton, satisfying equation (3.53). The equilibrium quantity of GM seed decreases from 0.69 tons without any policy tool to 0.37 tons with the subsidy. The value of social welfare in this case is equal to that in case (iii) with tax, \$6817. Figure 4.3 shows the net returns functions of the producer in case (iv), which is similar to Figure 3.13 in chapter 3.

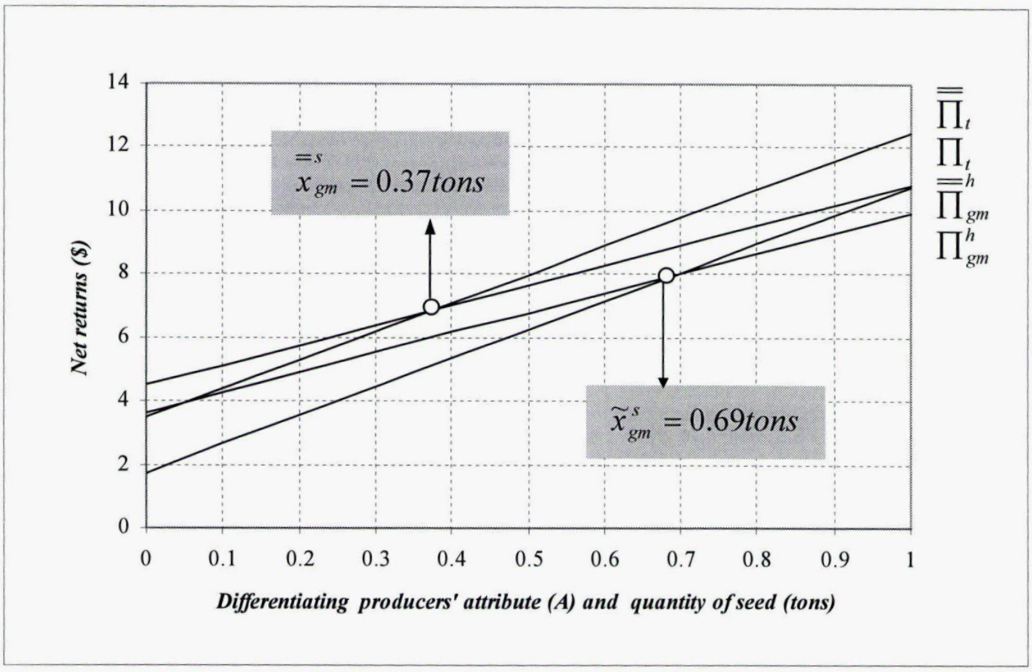

Figure 4.3: Illustration of case (iv) under perfect enforcement using numerical analysis

Figure 4.4 compares the social welfare in the four cases under perfect enforcement. It is observed that the values of social welfare achieved in the two policy regimes are equal under perfect enforcement scenario. This reconfirms the analytical results presented in

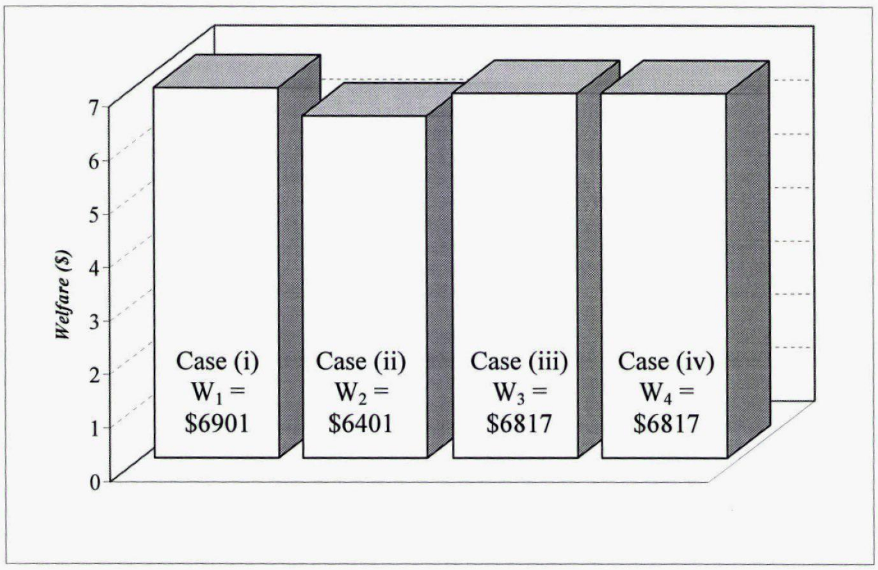

Figure 4.4: Welfare comparison under perfect enforcement with numerical analysis

chapter 3. However, government's decision about which policy to adopt might depend on distributional differences.

As can be observed from the numerical analysis, the value of social welfare achieved using either tax or subsidy, i.e., \$6817, is lower than that achieved under the benchmark case of Giannakas (2002) or case (i) in the current analysis, i.e., \$6901, but is higher than that reached in case (ii), \$6401. Thus, the current analysis shows that in the presence of the negative external effects arising from the GM variety of seed, a government policy such as a per unit tax or subsidy to address the externality is capable of raising domestic welfare under the perfect enforcement of IPRs.

4.2.2 Policy decision under imperfect enforcement scenario

Using the same parameters as presented in Table 4.2, a numerical analysis for imperfect enforcement of IPR is carried out to illustrate the analytical findings. For easy

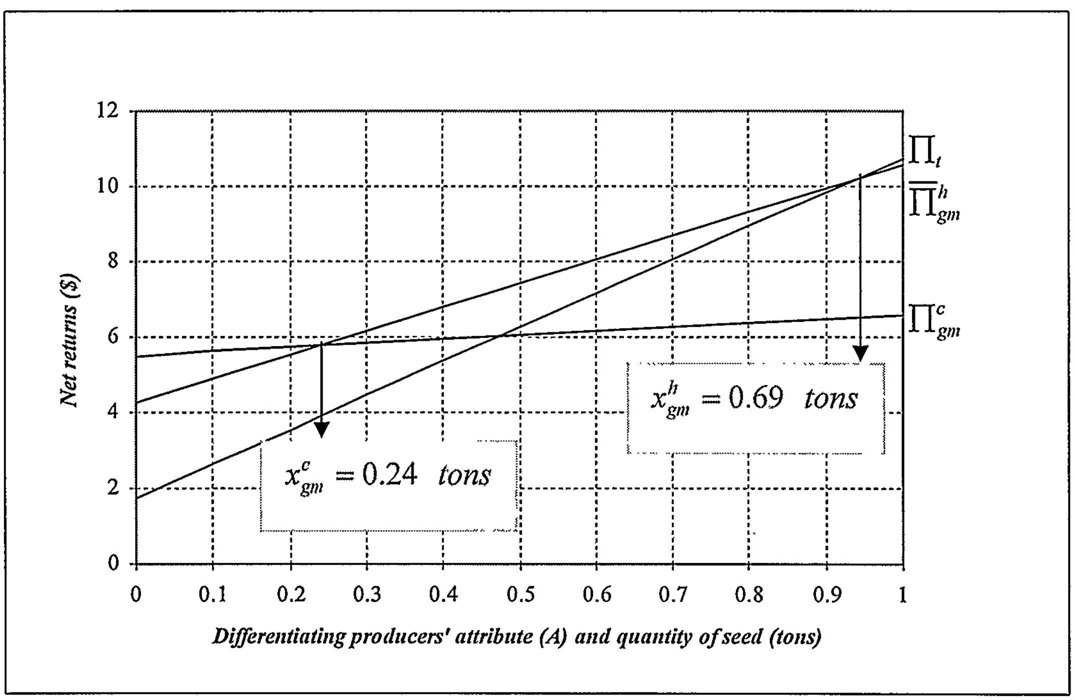

Figure 4.5: Illustration of cases (v) and (vi) under imperfect enforcement using numerical analysis

understanding, the four cases are considered in order. Figure 4.5 presents the net returns functions of the producers in case (v) where damages are yet to appear. Table 4.1 assumes that the producers face a 40% probability of getting audited while producing illegal GM seed, i.e., $\delta_0 = 0.4$ and that the level of penalty on getting caught, ρ is set at \$13000 per ton times that producer's A value. The price of GM seed in this case is \$1734, satisfying equation (3.26) and the equilibrium quantity of total GM seed is 0.93 tons, of which 0.69 tons is purchased, i.e., acquired legally and 0.24 tons is acquired illegally. Total value of producers' surplus in this case is calculated at \$7569 and that of social welfare is \$6815. Figure 4.5 corresponds to Figure 3.7 in chapter 3.

Case (vi) captures the specific effects of the negative externalities caused by the GM seed on social welfare. Other parameters remaining unchanged, the constant c in equation (3.34) is assumed to be equal to \$720/ton, and therefore, the value of the externality caused due to the use of GM seed turns out to be \$671. Consequently, social welfare drops to \$6144. By assumption, price and quantity of GM seed remain at the earlier

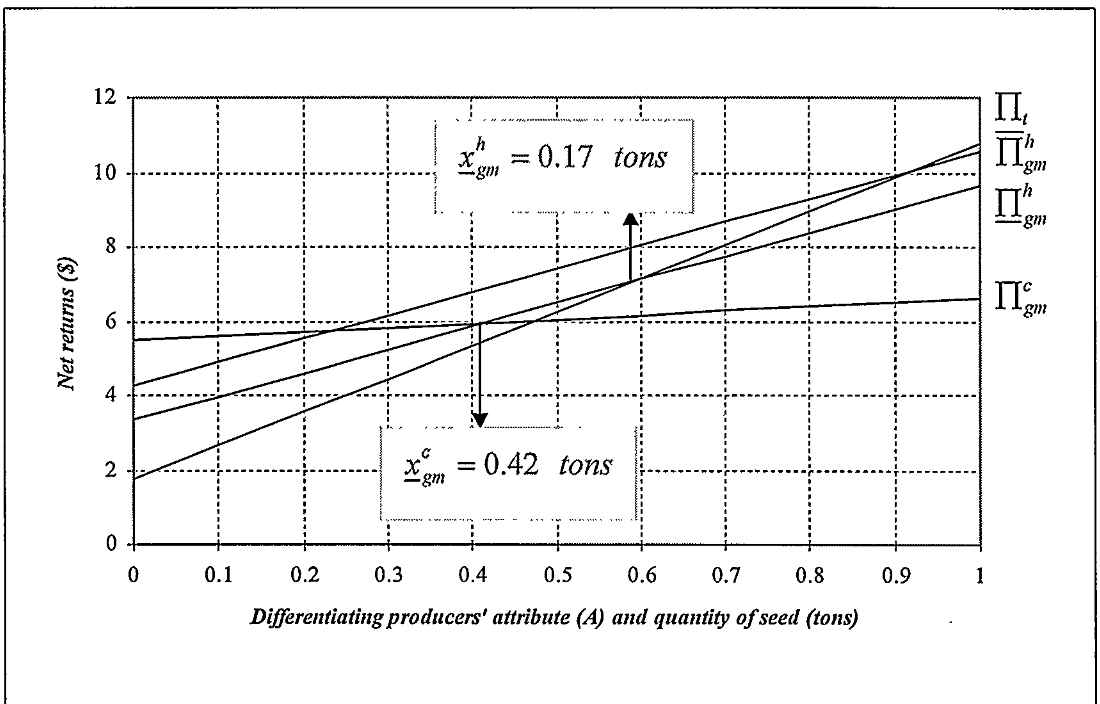

Figure 4.6: Illustration of case (vii) under imperfect enforcement using numerical analysis

levels. Figure 4.5 represents this scenario as well.

Figure 4.6 illustrates case (vii), i.e., tax (at rate τ_1) as a government policy to counter negative externalities under imperfect enforcement of the innovator's rights using the parameters specified in Table 4.2. Assuming δ_0 to be 40% as before, the optimal level of tax is $1850 per ton of GM seed usage in this case. The price of GM seed faced by the producers is $2659/ ton and the total GM seed usage is 0.59 tons, of which the quantity of legal GM seed is 0.17 tons and that of illegal GM seed is 0.42 tons. The value of surplus accruing to the producers drops to $7167. The value of total social welfare is calculated at $6613. Figure 4.6 in the present analysis parallels Figure 3.8 in the analysis carried out in chapter 3.

In Figure 4.7, illustration of case (viii) is presented. This case describes the use of subsidy (η_1) per unit of traditional seed purchased as a policy measure to internalize the externalities. Using the parameters in Table 4.2, the optimal level of subsidy turns out to

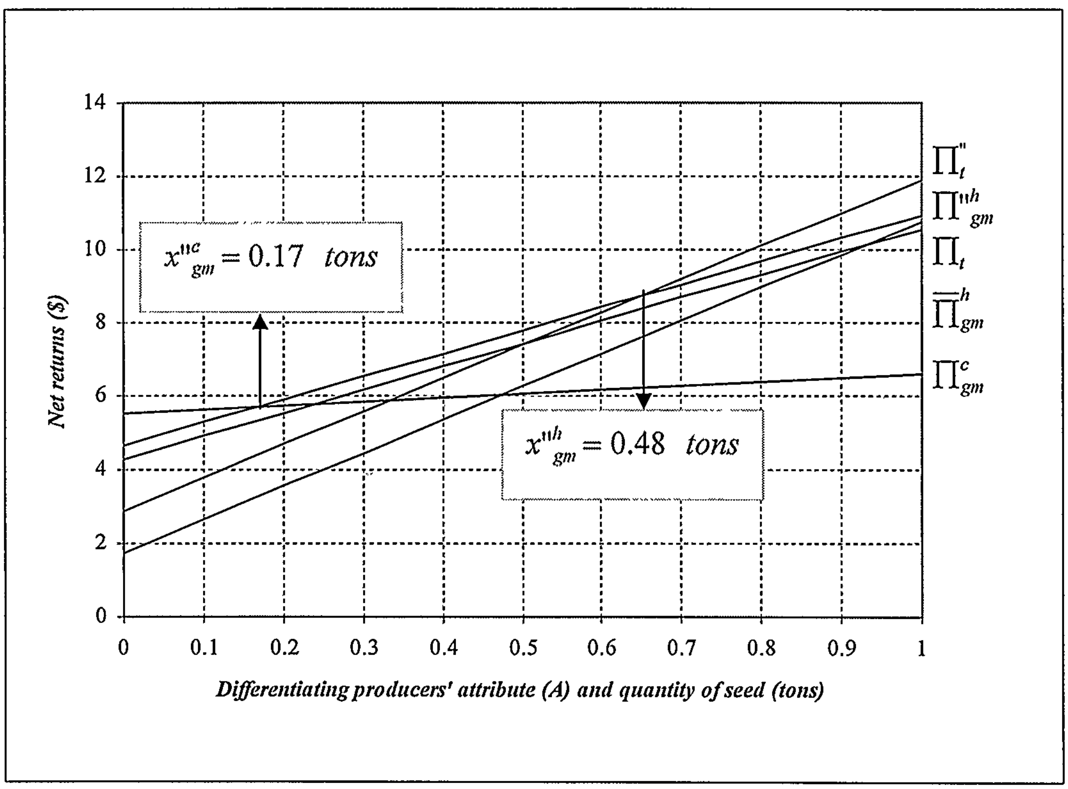

Figure 4.7: Illustration of case (viii) under imperfect enforcement using numerical analysis

be \$1141. The revised price of GM seed is \$1359/ ton. The equilibrium quantity of GM seed is 0.65 tons which consists of approximately 0.48 tons of legal seed and 0.17 tons of illegal seed. The value of producers' surplus is calculated to be \$8029 and that of social welfare is \$6332. For comparison with the analytical results in chapter 3, Figure 4.7 corresponds to Figure 3.14.

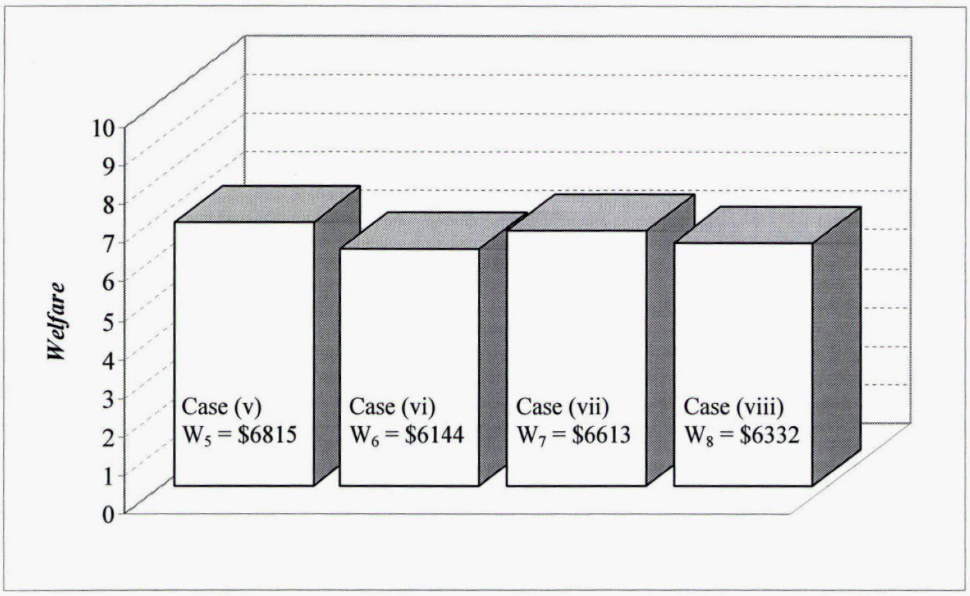

Figure 4.8: Welfare comparison under imperfect enforcement with numerical analysis

Figure 4.8 below presents the comparisons of the welfare levels achieved under different policy regimes of imperfect enforcement, using the parameters of Table 4.2. As can be observed from the figure, the value of social welfare is the highest with tax, i.e., case (vii). Subsidy yields higher social welfare compared with the 'do nothing' scenario of case (vi).

4.3 Summary and conclusions

Section 4.1 of this chapter discusses the major assumptions adopted for analysis in chapter 3. More importantly, the assumptions which differ from Giannakas (2002) to some extent are described and clarified. As an example, it is shown that in Giannakas (2002), the problem is structured in such a way that the probability of detecting cheating

(δ) under imperfect enforcement of IPRs enters as a choice variable for the developing country government. In the present analysis, the host government's aim is to choose the optimal policy instrument in the face of perfect or imperfect enforcement of IPRs, with the enforcement effort being constant in the short run. Finally, a numerical simulation has been carried out to illustrate various key results of the analytical model of chapter 3 and to present these results more clearly and completely.

	Case (i)	Case (ii)	Case (iii)	Case (iv)	Case (v)	Case (vi)	Case (vii)	Case (viii)
Price of GM seed faced by domestic producers ($/ton)	2375	2375	3240	1510	1734	1734	2659	1359
Quantity of legal GM seed (tons)	0.69	0.69	0.37	0.37	0.69	0.69	0.17	0.48
Quantity of illegal GM seed (tons)	NA[1]	NA	NA	NA	0.24	0.24	0.42	0.17
Quantity of traditional seed (tons)	0.31	0.31	0.63	0.63	0.07	0.07	0.41	0.35
Tax or subsidy rate per unit ($/ton)	NA	NA	1730	1730	NA	NA	1850	1141
Producers' surplus ($)	6901	6901	6439	8169	7569	7569	7167	8029
Externality ($)	NA	-500	-269	-269	NA	-671	-424	-467
Enforcement cost ($)	NA	NA	NA	NA	-900	-900	-900	-900
Expected penalty ($)	NA	NA	NA	NA	146	146	448	71
Tax revenue or subsidy payment ($)	NA	NA	647	-1083	NA	NA	322	-401
Innovator's rent ($)	[1302]	[1302]	[378]	[378]	[857]	[857]	[54]	[557]
Social welfare ($)[2]	6901	6401	6817	6817	6815	6144	6613	6332

Table 4.3: Numerical illustration of cases (i) through (viii)

[1] NA: Not applicable

[2] Social welfare in the last row is derived by adding (or subtracting) producers' surplus, (externality), (enforcement costs) and tax revenue or (subsidy payment). Innovator's rent makes no contribution to domestic social welfare.

CHAPTER FIVE: CONCLUSIONS

This chapter summarizes the findings of this research and describes possibilities for further research. In the next section, a summary of the existing economic models, which are discussed in chapter 2, is presented. Section 5.2 presents the findings of the current research, which are analyzed in chapters 3 and 4. In section 5.3, directions for future research are enumerated.

5.1 Summary of existing economic models

In chapter 2, a number of existing models are discussed which deal with the welfare implications of enforcement of intellectual property rights (IPRs) in the developing countries. In particular, these models analyze the effects on trade relations between the North and the South, which depend on the extent of intellectual property protection available in the South. A special emphasis is laid on the economic analysis of Giannakas (2002), in which it is shown that the developing country is better off, in terms of social welfare, by enforcing IPRs imperfectly. To be more precise, Giannakas (2002) shows that when a developing country government decides to allow the importation of a new variety of genetically modified (GM) seed from a developed country innovator, the developing country gains more by only partially enforcing the innovator's rights.

In the case of perfect enforcement, every user of the imported GM variety has to purchase the seed at a price set by the innovator, who is a monopolist in the market for GM seed. This enables the innovator to repatriate economic rent to the foreign country. Repatriation of host country resources in the form of rent by the foreign monopolist can be interpreted as a loss in social welfare of the developing country. On the other hand, when the "host" government implements IPRs imperfectly, there is a possibility of acquiring the GM seed through illegal means, such as black markets, reverse engineering or using seeds from last season's harvest. Under the model's assumptions about imperfect enforcement, there is always at least one crop producer in the developing country who finds it profitable to use the illegal source, no matter how high is the penalty on cheating, ex post. Therefore, in order to maximize profit with a reduction in effective indirect demand, the foreign innovator responds by lowering the price of the GM seed to some extent. The crop producers in the developing country, who acquire the GM seed legally, gain producers' surplus as the price of the GM seed is lower under imperfect enforcement. Giannakas (2002) describes this phenomenon as a positive externality enjoyed by the "host" government under imperfect enforcement.

5.2 Summary of the current research

The current model, presented in chapters 3 and 4 can be viewed as an extension and modification of Giannakas' (2002) work. This model takes into account one or more of the possible *negative externalities* that may be created in the process of using GM seed, such as loss of agricultural biodiversity, loss of traditional knowledge of the farming community in the developing world, and potential negative effects on public health. As explained in chapter 2, plantation of GM crop on a vast area may cause loss of agricultural diversity of crop genetic resources where diversity is an important component for healthy sustenance of the ecosystem. Moreover, farming communities in the developing countries acquire special knowledge about the environment and develop diverse crop varieties best suited for the particular region. When the GM seeds are introduced to these farmers who begin to use them extensively, the farmers tend to lose their folk knowledge and thus the problem of environmental homogeneity is further aggravated. In addition, there may be concern among people about the consumption of GM components in the form of food, if the GM crop is a food crop.

In the present analysis, these (perceived or actual) risks of agricultural biotechnology are regarded as negative external effects and are incorporated as a source of loss of the level of social welfare of the developing country. Policy tools such as a corrective tax per unit of GM seed purchased or a corrective subsidy per unit of traditional (non-GM) seed purchased are adopted by the host government to counter these negative external effects.

It is useful to note the important assumptions made to develop the model. Firstly, the model is short run in nature, e.g., entry/ exit decisions on the part of the domestic producers or foreign innovator are assumed away. Incorporating entry/ exit decisions would lead to different outcomes as the structure of the game tree would change.

It is also assumed that the developing country referred to in the model is a small open economy in the sense that the prices of both the GM crop and the traditional crop are taken by this economy as given. This assumption about constant output price simplifies the mathematical model and helps focus the analysis on the specific effects of the changes in seed prices alone. A non-constant output price would lead to a more complicated analytical scenario which could be investigated as a part of the further research.

The damage component in the model, characterizing the negative externality, has been computed using a simple linear relationship. This is done to keep the analysis simple. The validity of this assumption as a representation of actual harm associated with a specific type of GM crop would have to be verified empirically.

Another major assumption in the model is that of a fixed probability of catching the producers who cheat. In a developing country the total available resources may be limited so that the government would have little control over the probability of catching the producers in a given time period. The probability of catching cheating is directly related to the amount of resources allocated towards it.

The current analysis models the strategic, sequential interaction of the host government, the foreign innovator, and the domestic producers. The agents' interactions are modeled as a non-cooperative game in a small open economy. Closed form analytical solutions under perfect and imperfect regimes derived in chapter 3 describe the host government's optimal choice of tax or subsidy. Due to the existence of more than one source of market failure, namely, foreign monopolist and imperfect IPR enforcement, the 'first best' outcome is not achieved with a single corrective mechanism under imperfect enforcement. Adoption of a policy instrument does not lead to the 'second best' outcome because of the repatriation of the monopolist's rent by the foreign country.

The results of the model are explained and illustrated using numerical simulations presented in chapter 4. In building this numerical analysis, hypothetical values are assigned to the parameters of the model such that they follow the behavior of the net returns functions of the producers as modeled in the analysis in chapter 3. In cases where specific analytical results are complicated and difficult to compare with others, numerical analysis seems useful.

The results of the current research can be summarized as follows. The socially optimal corrective tax on legal GM seed or corrective subsidy on traditional seed reduces total production of the GM crop, (with (cases (iii) and (iv)) or without (cases (vii) and (viii)) full enforcement of IPRs), relative to the no-policy instrument cases ((ii) and (vi)). Under perfect enforcement, the optimal level of the per unit corrective tax is equal in magnitude to the optimal level of corrective subsidy and the levels of social welfare achieved using the two policy tools are also equal. With imperfect enforcement, the optimal corrective tax (case (vii)) increases the portion of the GM crop that is produced with illegal seed, relative to the no-tax case (v). Provided that the monopolist faces a linear demand curve and constant short run marginal costs, the static incidence of the optimal corrective tax is shared equally (on a per unit basis) by the foreign monopolist and the domestic crop producers. For a given tax regime, the negative externalities that accompany the use of the GM seed variety are higher in magnitude under imperfect enforcement of the IPRs than under perfect enforcement of IPRs. Analytical results and numerical simulations suggest that under imperfect enforcement of IPRs, the optimal level of the corrective tax is more efficient in reducing the level of GM seed usage and thus internalizing the externality than the optimal level of the corrective subsidy. The corrective tax reduces the total quantity of GM seed usage but increases the quantity of GM seed acquired illegally. The corrective subsidy, on the other hand, reduces the total quantity of GM seed usage as well as the quantity of illegally acquired GM seed. This causes the social welfare to increase more under tax than under the subsidy.

5.3 Scope for future research

The present analysis can be used as the building block for further research in a number of directions. The current research can be extended to carry out sensitivity test or an empirical analysis to strengthen the results already derived. The current analysis can also be considered as a basis for some future work which could have completely different implications.

A sensitivity analysis may be carried out which would be an improvement over the current research as this would mean testing the robustness of the current model by examining the validity of the various assumptions. As an example, in the current analysis, a simple mathematical function has been assigned to characterize the negative externality arising out of GM seed usage. One of the issues to be dealt with in the sensitivity analysis of the model might be examining the changes in the results of the model with complex functional forms for negative externality.

In addition, an empirical analysis based on the current research would involve examining the real world application of the public policies discussed here. One possible methodology for this may be to carry out case studies of country-specific problems. This is important from the point of view of the critical and unique economic conditions of the developing countries of the world. The case studies would help understand the validity of the assumptions made and the implications of the policy tools prescribed specific to the individual countries considered. In particular, this analysis would reveal whether a single corrective policy instrument is best suited for the developing country in question, or a combination of different policy tools needs to be applied.

This thesis integrates the issues of agricultural biotechnology and application of intellectual property rights in the context of a developing country. This is carried out using an analytical framework which includes a foreign monopoly and domestic producers who are heterogeneous in nature. The results of this analysis support the implementation of public policy in a strategic and sequential game theoretic setting, with optimizing behavior on the part of all other agents. The use of a corrective tax as a policy measure turns out to be more effective instrument than a corrective subsidy in the current analysis. However, there may be considerable scope to design the instruments separately or jointly to those used here, to derive more effective results.

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APPENDIX A: DERIVATION OF PRINCIPAL ANALYTICAL RESULTS

Section 3.1(A): Solving the innovator's problem in case (i)

The innovator as a monopolist determines the price of GM seed (p^s_{gm}) in the developing country market by maximizing short-run profits. Denoting innovator's profit by π, which consists of price of GM seed (p^s_{gm}) minus constant marginal cost of production (m) multiplied by the quantity of GM seed supplied (x^s_{gm}), the problem can be formally stated as

$$\max_{p^s_{gm}} \pi = (p^s_{gm} - m)x^s_{gm} \qquad (A1).$$

Since, $x^s_{gm} = \dfrac{(p_{gm} - p^s_{gm}) - (p_t - p^s_t)}{\gamma - \phi}$, from equation (3.5), the above objective function can be re-stated as

$$\pi = (p^s_{gm} - m)\frac{B - p^s_{gm}}{\gamma - \phi} \qquad (A2)\text{ , where, } B = p_{gm} - p_t + p^s_t.$$

The first order condition with respect to p^s_{gm} is

$$\frac{\partial \pi}{\partial p^s_{gm}} = 0 \quad \Rightarrow \quad \frac{B - 2p^s_{gm}}{\gamma - \phi} + \frac{m}{\gamma - \phi} = 0 \qquad (A3).$$

The second order condition for the optimization problem is given by

$$\frac{\partial^2 \pi}{\partial {p^s_{gm}}^2} < 0 \quad \Rightarrow \quad -\frac{2}{\gamma - \phi} < 0 \qquad (A4).$$

Solving (A3) for p^s_{gm}, gives

$$p^s_{gm} = \frac{p_{gm} - p_t + p^s_t + m}{2} = \frac{B + m}{2}\text{, which is equation (3.6) in section 3.1.1.}$$

Substituting p^s_{gm} into equation (3.5), the equilibrium quantity of GM seed becomes

$$x^s_{gm} = \frac{p_{gm} - p_t + p^s_t - m}{2(\gamma - \phi)} = \frac{B - m}{2(\gamma - \phi)}\text{, which is equation (3.7).}$$

Note on Section 3.1 (B):

This is an output created by the *Mathematica* software (version 2.2) used for simplifying analytical calculations. First the net returns functions are entered, shown by π_t and π_h. For notational simplicity, p_t^s is written as p_s, $\prod_{gm}^h$ is written as π_h, and p_{gm}^s is denoted as $\hat{p}$. Similarly, to avoid complex terms, B is substituted for $p_{gm} - p_t + p_t^s$, which is a constant. *PS* here denotes PS_1. The last expression for PS simplifies to equation (3.9).

Section 3.1 (B) : Calculating PS in case (i)

$\pi_t = p_t - p_s + \gamma * A;$

$\pi_h = p_{gm} - \hat{p} + \phi * A;$

$A_{gm} = \frac{B - \hat{p}}{\gamma - \phi};$

$\hat{p} = \frac{B + m}{2};$

$PS = \int_0^{A_{gm}} \pi_h \, dA + \int_{A_{gm}}^{1} \pi_t \, dA$

$$\frac{\gamma}{2} - \frac{\left(B + \frac{1}{2}(-B - m)\right)^2 \gamma}{2(\gamma - \phi)^2} + \frac{\left(B + \frac{1}{2}(-B - m)\right)^2 \phi}{2(\gamma - \phi)^2} + \frac{\left(B + \frac{1}{2}(-B - m)\right)(-B - m + 2 p_{gm})}{2(\gamma - \phi)} - p_s + p_t - \frac{\left(B + \frac{1}{2}(-B - m)\right)(-p_s + p_t)}{\gamma - \phi}$$

FullSimplify[PS]

$$\frac{1}{8(\gamma - \phi)}\left(-3B^2 + 2Bm + m^2 + 4\gamma^2 - 4\gamma\phi + 4(B - m)p_{gm} + 4(B - m - 2\gamma + 2\phi)(p_s - p_t)\right)$$

The last expression for *PS* can be simplifies as follows

$$PS = \frac{1}{8(\gamma-\phi)}[-3B^2 + 2Bm + m^2 + 4\gamma^2 - 4\gamma\phi + 4(B-m)p_{gm} + 4(B-m-2\gamma+2\phi)(p_s - p_t)]$$

$$\Rightarrow PS = \frac{1}{8(\gamma-\phi)}[-8(\gamma-\phi)(p_s - p_t) - 3B^2 + 2Bm + m^2 + 4\gamma^2 - 4\gamma\phi$$
$$+ 4(B-m)(p_{gm} - p_t + p_s)]$$

Substituting $B = p_{gm} - p_t + p_s$, the above expression can be simplified to

$$\Rightarrow PS = \frac{1}{8(\gamma-\phi)}[-8(\gamma-\phi)(p_s - p_t) - 3B^2 + 2Bm + m^2 + 4\gamma^2 - 4\gamma\phi + 4B^2 - 4Bm]$$

$$\Rightarrow PS = \frac{1}{8(\gamma-\phi)}[-8(\gamma-\phi)(p_s - p_t) + B^2 - 2Bm + m^2 + 4\gamma(\gamma-\phi)]$$

$\Rightarrow PS = p_t - p_s + \frac{\gamma}{2} + \frac{(B-m)^2}{8(\gamma-\phi)}$, which is equation (3.9).

Section 3.1(C): Solving the innovator's problem in case (iii)

The foreign innovator decides on the (pre-tax) price of GM seed ($\hat{p}^{s}_{gm}$) in the developing country market to maximize profits. In this case, as a policy measure, the developing country government has introduced a tax (τ_0) per unit of GM seed purchased. Denoting the innovator's profit by π, which is same as the innovator's rent, *IR*$_3$, it consists of the price of the GM seed ($\hat{p}^{s}_{gm}$) minus constant marginal cost of production (*m*) multiplied by the quantity of GM seed supplied ($\tilde{x}^{s}_{gm}$), and the problem can be formally stated as

$$\max_{\hat{p}^{s}_{gm}} \pi = (\hat{p}^{s}_{gm} - m)\tilde{x}^{s}_{gm} \qquad (A5).$$

From equation (3.13), $\tilde{x}^{s}_{gm} = \dfrac{p_{gm} - p_t + p^{s}_t - \tilde{p}^{s}_{gm}}{\gamma - \phi}$ and by definition, $\tilde{p}^{s}_{gm} = \hat{p}^{s}_{gm} + \tau_0$.

Thus, re-writing the innovator's objective function ,

$$\pi = (\hat{p}^{s}_{gm} - m)\frac{B - \hat{p}^{s}_{gm} - \tau_0}{\gamma - \phi} \qquad (A6), \text{ where } B = p_{gm} - p_t + p^{s}_t.$$

The first order condition with respect to $\hat{p}^{s}_{gm}$ is

$$\frac{\partial \pi}{\partial \hat{p}^{s}_{gm}} = 0 \quad \Rightarrow \quad \frac{B - 2\hat{p}^{s}_{gm} - \tau_0}{\gamma - \phi} + \frac{m}{\gamma - \phi} = 0 \qquad (A7),$$

and the second order condition for the optimization problem is

$$\frac{\partial^2 \pi}{\partial (\hat{p}^{s}_{gm})^2} < 0 \quad \Rightarrow \quad -\frac{2}{\gamma - \phi} < 0 \qquad (A8).$$

Solving (*A7*) for $\hat{p}^{s}_{gm}$,

$$\hat{p}^{s}_{gm} = \frac{p_{gm} - p_t + p^{s}_t + m - \tau_0}{2} = \frac{B + m - \tau_0}{2}, \text{ which is equation (3.14) in section 3.1.3.}$$

Therefore,

$$\tilde{p}^{s}_{gm} = \hat{p}^{s}_{gm} + \tau_0 = \frac{p_{gm} - p_t + p^{s}_t + m + \tau_0}{2} = \frac{B + m + \tau_0}{2} \text{ which confirms equation (3.15).}$$

Substituting the value of $\tilde{p}^{s}_{gm}$ in equation (3.13), gives

$\widetilde{x}_{gm}^{s} = \frac{p_{gm} - p_t + p_t^s - m - \tau_0}{2(\gamma - \phi)} = \frac{B - m - \tau_0}{2(\gamma - \phi)}$, which is equation (3.16).

Section 3.1(D): Solving PS_3 and the government's problem in case (iii)

Government in the developing country maximizes social welfare (W_3). In this case, the developing country government has introduced a tax (τ_0) per unit of GM seed purchased as a policy measure. Therefore, W_3 consists of surplus earned by the domestic producers (PS_3) minus negative externalities of various forms arising from GM crop production (D_3^{PE}) plus tax revenue (TR_3) earned by the government. The constraint in the optimization problem is a minimum innovator rent implying that the innovator's rent (IR_3) must be greater than some minimum level, r_3, so that the innovator finds it profitable to stay in the market. The government's problem can be presented formally as:

$$\begin{aligned} &\max_{\tau_0} W_3 = PS_3 - D_3^{PE} + TR_3, \\ &subject \;\; to \;\; IR_3 > r_3 \;\; (\geq 0). \end{aligned} \qquad \text{(A9)}$$

Producers' surplus is given by

$$PS_3 = \int_0^{\tilde{A}_{gm}} \tilde{\Pi}_{gm}^h \, dA + \int_{\tilde{A}_{gm}}^1 \Pi_t dA \qquad (A10).$$

Substituting $\Pi_t = p_t - p_t^s + \gamma A$ from equation (3.1), $\tilde{\Pi}_{gm}^h = p_{gm} - \tilde{p}_{gm}^s + \phi A$ from equation (3.12), and $\tilde{A}_{gm} = \dfrac{(p_{gm} - \tilde{p}_{gm}^s) - (p_t - p_t^s)}{\gamma - \phi}$ from equation (3.13), PS_3 can be re-written as

$$PS_3 = \int_0^{\frac{B-\tilde{p}_{gm}^s}{\gamma-\phi}} (p_{gm} - \tilde{p}_{gm}^s + \phi A) dA + \int_{\frac{B-\tilde{p}_{gm}^s}{\gamma-\phi}}^1 (p_t - p_t^s + \gamma A) dA \qquad (A11).$$

Evaluating the above integral,

$PS_3 = p_t - p_t^s + \dfrac{\gamma}{2} + \dfrac{(B - m - \tau_0)^2}{8(\gamma - \phi)}$, which is equation (3.17). Detailed step by step derivations are shown in the *Mathematica* output presented at the end of this section.

Kuhn-Tucker conditions

Consider the following maximization problem (see Varian, 2000):

$$\max_{x} \quad f(x)$$

$$subject \quad to \quad x \geq 0.$$

At a solution x*,

- $either\, f'(x^*) = 0 \quad and \quad x \geq 0 \qquad (A12),$
- $or\, x^* = 0 \quad and \quad f'(x^*) \leq 0 \qquad (A13).$

Equations (A12) and (A13) can be written together as a set of conditions as follows:

$$\left.\begin{array}{l} x^* f'(x^*) = 0 \\ f'(x^*) \leq 0 \\ x^* \geq 0 \end{array}\right\} \quad \text{(A14)}$$

The above argument can now be generalized to the following problem:

$$\max \quad f(x),$$

$$subject \quad to \quad g(x) \leq c.$$

Let $M(x) = f(x) - \lambda[g(x) - c] \qquad (A15).$

From the above equation, maximizing *f(x)* subject to the constraint is equivalent to maximizing *M(x)*. Thus the first order conditions can be written as:

$$\left.\begin{array}{l} M'(x^*) \leq 0, \\ x^* \geq 0, \\ x^* M'(x^*) = 0, \end{array}\right\} \quad \text{(A16)}$$

and

$$\left.\begin{array}{l} g(x^*) - c \leq 0, \\ \lambda \geq 0, \\ \lambda(g(x^*) - c) = 0. \end{array}\right\} \quad \text{(A17)}$$

The present problem is to maximize social welfare W_3, subject to a minimum innovator's rent constraint, i.e.,

$$\left.\begin{array}{l} \max\limits_{\tau_0} W_3(\tau_0) = PS_3 - D_3^{PE} + TR_3, \\ subject \quad to \quad IR_3(\tau_0) > r_3 \quad (\geq 0), \end{array}\right. \qquad \text{(A18)}$$

where, $D_3^{PE} = c \times \widetilde{x}_{gm}^{s}$ is given by equation (3.18), $TR_3 = \tau_0 \times \widetilde{x}_{gm}^{s}$, is given by equation (3.19) and $IR_3 = \left(\hat{p}_{gm}^{s} - m\right) \times \widetilde{x}_{gm}^{s}$, is given by equation (3.20).

Comparing with equation (A15), the following function (Lagrangian) can be set as:

$$L(\tau_0) = W_3(\tau_0) + \lambda[IR_3(\tau_0) - r_3] \qquad (A19).$$

The Kuhn-Tucker conditions for the above problem are:

$$\left.\begin{aligned} &L'(\tau_0^*) \leq 0, \\ &\tau_0^* \geq 0, \\ &\tau_0^* L'(\tau_0^*) = 0, \end{aligned}\right\} \quad \text{(A20)}$$

and

$$\left.\begin{aligned} &IR_3'(\tau_0^*) - r_3 \leq 0, \\ &\lambda \geq 0, \\ &\lambda(IR_3'(\tau_0^*) - r_3) = 0. \end{aligned}\right\} \quad \text{(A21)}$$

In this case, the optimal condition is characterized by a slack constraint since $IR_3 > r_3$. Solving Kuhn-Tucker conditions,

$$L'(\tau_0^*) = \frac{c}{2(\gamma-\phi)} + \frac{p_t - p_t^s}{2(\gamma-\phi)} + \frac{B + \frac{1}{2}(-B - m - \tau_0)}{2(\gamma-\phi)} - \frac{-B - m + 2p_{gm} - \tau_0}{4(\gamma-\phi)} - \frac{\tau_0}{2(\gamma-\phi)}$$
$$- \frac{(-B + \frac{1}{2}(B + m + \tau_0))}{2(\gamma-\phi)^2}(\gamma-\phi) \qquad (A22).$$

Solving the set of conditions in (A20) and A(21) and simplifying,

$\tau_0^* = \frac{1}{3}(p_{gm} - p_t + p_t^s + 2c - m)$, which is equation (3.21) in section 3.1.3.

The *Mathematica* output is presented to show detailed derivations of the analytical results. First the net returns functions are entered, shown by π_t and π_{gm}. For notational simplicity, Π_t is expressed as π_t, p_t^s as p_s, $\widetilde{\Pi}_{gm}^{h}$ as π_{gm}, , $\widetilde{p}_{gm}^{s}$ as $\overline{p}$ and $\widetilde{A}_{gm}$ as A_{gm}. Similarly, to avoid complex terms, B is substituted for $(p_{gm} - p_t + p_t^s)$, which is a constant. *PS* here denotes PS_3. The final expression for PS can be shown to simplify to equation (3.17).

For solving the optimal tax function, the government's problem is also solved using *Mathematica.* The negative externality is denoted as the damage, the tax revenue as revenue, the innovator's rent as rent and the social welfare function as SWF. Next, differentiating and solving the Lagrangian with respect to λ and τ_0 respectively, the optimal tax rate simplifies to equation (3.21).

Section 3.1 (D) : Calculating producers' surplus (PS_3) and solving the government's problem in case (iii)

$\pi_t = p_t - p_s + \gamma * A;$

$\pi_{gm} = p_{gm} - \overline{p} + \phi * A;$

$A_{gm} = \dfrac{B - \overline{p}}{\gamma - \phi};$

$\overline{p} = \dfrac{B + m + \tau_0}{2};$

$PS = \int_0^{A_{gm}} \pi_{gm}\, dA + \int_{A_{gm}}^1 \pi_t\, dA;$

FullSimplify[PS]

$$\frac{1}{8(\gamma-\phi)}\left(-3B^2 + 2Bm + m^2 + 4\gamma^2 - 4\gamma\phi + 4(B - m - 2\gamma + 2\phi)(p_s - p_t) + 4p_{gm}(B - m - \tau_0) + 2(B + m - 2p_s + 2p_t)\tau_0 + \tau_0^2\right)$$

$Damage = c * A_{gm};$

$Revenue = \tau_0 * A_{gm};$

$Rent = (\overline{p} - m) * A_{gm};$

General::spell1 : Possible spelling error: new symbol name "Rent" is similar to existing symbol "Rest".

SWF = PS − Damage + Revenue;

Lagrange = SWF + λ * (Rent − r);

∂_λ Lagrange;

sol1 = Solve[∂_λ Lagrange * λ == 0, λ]

{{λ → 0}}

λ = 0;

∂_{τ_0} Lagrange;

sol2 = Solve[∂_{τ_0} Lagrange * τ_0 == 0, τ_0]

$$\left\{\{\tau_0 \to 0\}, \left\{\tau_0 \to \frac{2B + 2c + \frac{B\gamma}{\gamma-\phi} - \frac{m\gamma}{\gamma-\phi} - \frac{B\phi}{\gamma-\phi} + \frac{m\phi}{\gamma-\phi} - 2p_{gm} - 2p_s + 2p_t}{2 + \frac{\gamma}{\gamma-\phi} - \frac{\phi}{\gamma-\phi}}\right\}\right\}$$

FullSimplify[sol2]

$$\left\{\{\tau_0 \to 0\}, \left\{\tau_0 \to \frac{1}{3}(3B + 2c - m - 2p_{gm} - 2p_s + 2p_t)\right\}\right\}$$

Section 3.2(A): Solving the innovator's problem and producers' surplus (PS_5) in case (v)

The foreign innovator's objective is to maximize profits (π) and in order to do that, determine the price of GM seed ($\bar{p}^s_{gm}$) under imperfect enforcement of IPRs. Formally, the problem can be presented as

$$\max_{\bar{p}^s_{gm}} \pi = (\bar{p}^s_{gm} - m)x^h_{gm} \qquad \text{(A23).}$$

Total GM seed purchased legally (x^h_{gm}) can be derived by noting that there is a one-to-one relationship between producers' attribute (A) and the quantity of seed usage. Therefore, subtracting the quantity of illegal GM seed, given by equation (3.24), i.e., $A^c_{gm} = \dfrac{\bar{p}^s_{gm} - m}{\delta_0 \rho}$ from the quantity of total GM seed, given by equation (3.25), i.e., $A_{gm} = \dfrac{p_{gm} - p_t + p^s_t - \bar{p}^s_{gm}}{\gamma - \phi}$, the quantity of legal GM seed is obtained as

$$x^h_{gm} = A_{gm} - A^c_{gm} = \frac{\delta_0 \rho (p_{gm} - p_t + p^s_t) - \bar{p}^s_{gm}(\gamma - \phi + \delta_0 \rho) + m(\gamma - \phi)}{(\gamma - \phi)\delta_0 \rho}.$$

Thus, objective function can be re-written as

$$\max_{\bar{p}^s_{gm}} \pi = (\bar{p}^s_{gm} - m)\frac{\delta_0 \rho B - \bar{p}^s_{gm}(\gamma - \phi + \delta_0 \rho) + m(\gamma - \phi)}{(\gamma - \phi)\delta_0 \rho} \qquad (A24)\text{, where,}$$

$B = p_{gm} - p_t + p^s_t$.

The first order condition is given by

$$\frac{\partial \pi}{\partial \bar{p}^s_{gm}} = 0 \quad \Rightarrow \quad \frac{B}{(\gamma - \phi)} - \frac{2\bar{p}^s_{gm}(\gamma - \phi + \delta_0 \rho)}{(\gamma - \phi)\delta_0 \rho} + \frac{m(\gamma - \phi + \delta_0 \rho) + m(\gamma - \phi)}{(\gamma - \phi)\delta_0 \rho} = 0 \qquad (A25)$$

,

and the second order condition is given by

$$\frac{\partial^2 \pi}{\partial (\bar{p}^s_{gm})^2} < 0 \quad \Rightarrow \quad -\frac{2(\gamma - \phi + \delta_0 \rho)}{(\gamma - \phi)\delta_0 \rho} < 0 \qquad (A26).$$

Solving the first order condition in (*A25*),

$$\overline{p}^{s}_{gm} = \frac{\delta_0\rho(p_{gm} - p_t + p_t^s) + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0\rho)} + \frac{m}{2} = \frac{\delta_0\rho B + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0\rho)} + \frac{m}{2},$$ which is equation (3.26) in section 3.2.1. Substituting the value of $\overline{p}^{s}_{gm}$ in equations (3.24) and (3.25) respectively, and subtracting A^c_{gm} from A_{gm},

$$x^h_{gm} = A_{gm} - A^c_{gm} = \frac{(p_{gm} - p_t + p_t^s - m)}{2(\gamma - \phi)} = \frac{(B - m)}{2(\gamma - \phi)},$$ which is equation (3.27). From equation (3.24), the quantity of illegally acquired GM seed is calculated to be,

$$x^c_{gm} = \frac{(p_{gm} - p_t + p_t^s - m)}{2(\gamma - \phi + \delta_0\rho)} = \frac{(B - m)}{2(\gamma - \phi + \delta_0\rho)},$$ which is equation (3.28).

Calculations for producer surplus (PS_5):

The 'Mathematica' output is presented to show detailed derivations of the analytical results. First the net returns functions are entered, shown by *πt, πhgm* and *πcgm*. For notational simplicity, $\prod_t$ is expressed as *πt*, p_t^s as *pts*, $\overline{\prod}^h_{gm}$ as *πhgm*, , $\overline{p}^s_{gm}$ as *pgms*, $\prod^c_{gm}$ as *πcgm*, A_{gm} as *Agm*, and A^c_{gm} as *Ac*. Similarly, to avoid complex terms, B is substituted for ($p_{gm} - p_t + p_t^s$), which is a constant. *PS* here denotes PS_5. The final expression for PS can be shown to simplify to equation (3.30).

Imperfect enforcement of IPRs: calculating producers' surplus (PS_5)

$\pi t = pt - pts + \gamma * A;$

$\pi hgm = pgm - pgms + \phi * A;$

General::spell1 : Possible spelling error: new symbol name "pgms" is similar to existing symbol "pgm".

$\pi cgm = pgm + \phi * A - m - \delta_0 * \rho * A;$

General::spell1 : Possible spelling error: new symbol name "πcgm" is similar to existing symbol "πhgm".

$$Ac = \frac{pgms - m}{\delta_0 * \rho};$$

$$Agm = \frac{B - pgms}{\gamma - \phi};$$

$$pgms = \frac{\delta_0 * \rho * B + m * (\gamma - \phi)}{2 * (\gamma - \phi + \delta_0 * \rho)} + \frac{m}{2};$$

$$PS = \int_0^{Ac} \pi cgm \, dA + \int_{Ac}^{Agm} \pi hgm \, dA + \int_{Agm}^{1} \pi t \, dA;$$

FullSimplify[PS]

$$(4 (-B^2 + m^2 + 2 B (pgm - pt + pts) - 2 m (pgm - pt + pts) + (2 pt - 2 pts + \gamma) (\gamma - \phi)) (\gamma - \phi) + \rho (-3 B^2 + m^2 - 4 m (pgm - pt + pts) + 2 B (m + 2 (pgm - pt + pts)) + 4 (2 pt - 2 pts + \gamma) (\gamma - \phi)) \delta_0) / (8 (\gamma - \phi) (\gamma - \phi + \rho \delta_0))$$

Section 3.2(B): Solving the innovator's problem in case (vii)

The foreign innovator is assumed to maximize profits (π) and determine the price of GM seed ($\breve{p}^s_{gm}$) to be charged in the developing country market, under the imperfect enforcement of IPRs. The innovator's problem can be stated as,

$$\max_{\breve{p}^s_{gm}} \pi = (\breve{p}^s_{gm} - m)\underline{x}^h_{gm} \qquad (A27).$$

Note that $\underline{x}^h_{gm}$ has been substituted by $\underline{x}^h_{gm} = A^{(new)}_{gm} - A^{c(new)}_{gm}$; $A^{(new)}_{gm}$ and $A^{c(new)}_{gm}$ are given by equations (3.47) and (3.48) respectively.

The objective function can be re-written as

$$\max_{\breve{p}^s_{gm}} \pi = (\breve{p}^s_{gm} - m)\frac{\delta_0\rho B - (\breve{p}^s_{gm} + \tau_1)(\gamma - \phi + \delta_0\rho) + m(\gamma - \phi)}{(\gamma - \phi)\delta_0\rho} \qquad (A28).$$

The first order condition for the optimization problem is given by

$$\frac{\partial \pi}{\partial \breve{p}^s_{gm}} = 0 \quad \Rightarrow \quad \frac{B}{(\gamma - \phi)} - \frac{2\breve{p}^s_{gm}(\gamma - \phi + \delta_0\rho)}{(\gamma - \phi)\delta_0\rho} + \frac{m(\gamma - \phi + \delta_0\rho)}{(\gamma - \phi)\delta_0\rho} + \frac{m}{\delta_0\rho}$$
$$- \frac{\tau_1(\gamma - \phi + \delta_0\rho)}{(\gamma - \phi)\delta_0\rho} = 0 \qquad (A29),$$

and the second order condition is given by

$$\frac{\partial^2 \pi}{\partial (\breve{p}^s_{gm})^2} < 0 \quad \Rightarrow \quad -\frac{2(\gamma - \phi + \delta_0\rho)}{(\gamma - \phi)\delta_0\rho} < 0 \qquad (A30).$$

Solving for $\breve{p}^s_{gm}$ from *(A29)*,

$$\breve{p}^s_{gm} = \frac{\delta_0\rho(p_{gm} - p_t + p^s_t) + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0\rho)} - \frac{\tau_1 - m}{2},$$ which is equation (3.37).

Substituting the value of $\breve{p}^s_{gm}$ in equations (3.47) and (3.48) respectively and subtracting $A^{c(new)}_{gm}$ from $A^{(new)}_{gm}$, the post-tax legal GM seed usage would be

$$\underline{x}^h_{gm} = A^{(new)}_{gm} - A^{c(new)}_{gm}$$
$$= \frac{\delta_0\rho(p_{gm} - p_t + p^s_t - m) - \tau_1(\gamma - \phi + \delta_0\rho)}{2(\gamma - \phi)\delta_0\rho} = \frac{\delta_0\rho(B - m) - \tau_1(\gamma - \phi + \delta_0\rho)}{2(\gamma - \phi)\delta_0\rho},$$

which is equation (3.39) and the quantity of post-tax illegal GM seed would be

$$\underline{x}_{gm}^{c} = \frac{\delta_0\rho(p_{gm} - p_t + p_t^s - m) + \tau_1(\gamma - \phi + \delta_0\rho)}{2(\gamma - \phi + \delta_0\rho)\delta_0\rho} = \frac{\delta_0\rho(B - m) + \tau_1(\gamma - \phi + \delta_0\rho)}{2(\gamma - \phi + \delta_0\rho)\delta_0\rho}$$, which is equation (3.40).

Section 3.2(C): Solving for the producers' surplus (PS_7) and the government's problem in case (vii)

Government in the developing country maximizes social welfare (W_7) under imperfect enforcement of IPRs. In this case, the developing country government has introduced tax (τ_1) per unit of GM seed purchased as a policy measure. Therefore, W_7 consists of surplus earned by the domestic producers (PS_7), negative externalities of various forms arising from GM seed usage (D_7^{IE}), tax revenue (TR_7) earned by the government, enforcement cost (EC) and the expected revenue from penalty charges (F_7). The constraint in the optimization problem would be a minimum innovator rent implying that the innovator's rent (IR_7) would not be less than some minimum level r_7, so that the innovator finds it profitable to stay in the market. The government's problem can be formally stated as

$$\begin{aligned} &\max_{\tau_1} W_7 = PS_7 - EC - D_7^{IE} + TR_7 + F_7, \\ &subject\ \ to\ \ IR_7 > r_7 \ \ (\geq 0). \end{aligned} \qquad \text{(A31)}$$

Producer's surplus (PS_7) is given by

$$PS_7 = \int_0^{A_{gm}^{c(new)}} \prod_{gm}^c dA + \int_{A_{gm}^{c(new)}}^{A_{gm}^{(new)}} \underline{\prod}_{gm}^h dA + \int_{A_{gm}^{(new)}}^{1} \prod_t dA \qquad (A32).$$

Substituting $\prod_{gm}^c = p_{gm} + \phi A - \delta_0 \rho A - m$ from equation (3.22*A*), $\underline{\prod}_{gm}^h = p_{gm} - \underline{p}_{gm}^s + \phi A$ from equation (3.35), $\prod_t = p_t - p_t^s + \gamma A$ from equation (3.1), $A_{gm}^{c(new)} = \dfrac{\breve{p}_{gm}^s + \tau_1 - m}{\delta_0 \rho}$ from equation (3.48) and $A_{gm}^{(new)} = \dfrac{p_{gm} - p_t + p_t^s - (\breve{p}_{gm}^s + \tau_1)}{\gamma - \phi}$ from equation (3.47),

$$PS_7 = \int_0^{\frac{\breve{p}_{gm}^s + \tau_1 - m}{\delta_0 \rho}} (p_t + \phi A - \delta_0 \rho A - m) dA + \int_{\frac{\breve{p}_{gm}^s + \tau_1 - m}{\delta_0 \rho}}^{\frac{B - (\breve{p}_{gm}^s + \tau_1)}{\gamma - \phi}} (p_{gm} - \underline{p}_{gm}^s + \phi A) dA + \int_{\frac{B - (\breve{p}_{gm}^s + \tau_1)}{\gamma - \phi}}^{1} (p_t - p_t^s + \gamma A) dA$$

$= p_t - p_t^s + \frac{\gamma}{2} + \frac{\tau_1^2}{8\delta_0\rho} + \frac{3(B-m)^2}{8(\gamma-\phi+\delta_0\rho)} + \frac{(-B+m+\tau_1)^2}{8(\gamma-\phi)}$, which is equation (3.41). The step by step derivation of (3.44) is shown at the end of this section, using the results of *Mathematica.*

The damage function is given by $D_7^{IE} = c \times (\underline{x}_{gm}^h + \underline{x}_{gm}^c)$, which is equation (3.42). Tax revenue, denoted TR_7 is given by equation (3.43), $TR_7 = \tau_1 \times \underline{x}_{gm}^s$. Expected revenue from penalty (F_7) is given by $F_7 = \rho \int_0^{A_{gm}^{c(new)}} (\delta_0 A) dA$, which is equation (3.44). The enforcement cost EC is constant and is given by $EC = \alpha\delta_0 + \beta$. The innovator's rent IR_7 is given by $IR_7 = (\breve{p}_{gm}^s - m) \times (\underline{x}_{gm}^s)$, which is equation (3.45).

Setting up the Lagrangian of the government's problem,

$L = W_7 + \lambda(IR_7 - r_7)$, where λ is the Lagrange multiplier.

Kuhn-Tucker conditions for maximization are:

$$\left.\begin{array}{l} L'(\tau_1) \le 0, \\ \tau_1 \ge 0, \\ \tau_1 L'(\tau_1) = 0 \end{array}\right\} \quad \text{(A33)}$$

$$\left.\begin{array}{l} (IR_7 - r_7) \le 0, \\ \lambda \ge 0, \\ \lambda(IR_7 - r_7) = 0. \end{array}\right\} \quad \text{(A34)}$$

In this case, the optimal condition is characterized by a slack constraint since $IR_7 > r_7$. Solving the Kuhn-Tucker condition gives,

$$\tau_1^* = \delta_0\rho\left(\frac{4(p_{gm} - p_t + p_t^s) + 2c - 2m}{2\gamma - 2\phi + 3\delta_0\rho} + \frac{-(p_{gm} - p_t + p_t^s) + m}{\gamma - \phi + \delta_0\rho}\right)$$

$$= \delta_0\rho\left(\frac{4B + 2c - 2m}{2\gamma - 2\phi + 3\delta_0\rho} + \frac{-B + m}{\gamma - \phi + \delta_0\rho}\right)$$

which is equation (3.46).

Calculations for PS$_7$:

The *Mathematica* output is presented to show detailed derivations of the analytical results. First the net returns functions are entered, shown by π_t, π_h and π_c. For notational simplicity, $\prod_t$ is expressed as π_t, p_t^s as *pts*, $\underline{\prod}_{gm}^h$ as π_h, $\underline{p}_{gm}^s$ as $\bar{p}$, $\prod_{gm}^c$ as π_c, $A_{gm}^{(new)}$ as A_{gm}, and $A_{gm}^{c(new)}$ as A_{cgm}, $\breve{p}_{gm}^s$ is denoted by $\hat{p}$ and τ_1 is denoted by τ. Similarly, to avoid complex terms, B is substituted for ($p_{gm} - p_t + p_t^s$), which is a constant. *PS* here denotes *PS$_7$*. The final expression for PS$_7$ can be shown to simplify to equation (3.41).

For solving the optimal tax function, τ_1^*, the government's problem is also solved using *Mathematica*. The negative externality is denoted as the damage, the tax revenue as *TR*, the penalty function as *Fine*, the innovator's rent as *IR* and the social welfare function as *Welfare*. Next, differentiating and solving the Lagrangian with respect to λ and τ respectively, the optimal tax rate simplifies to equation (3.46).

Imperfect enforcement of IPRs – calculating producers' surplus (PS_7) and solving the government's problem in case (vii)

$\pi_t = \text{pt} - \text{pts} + \gamma * \text{A};$

$\pi_h = \text{pgm} - \overline{\text{p}} + \phi * \text{A};$

$\pi_c = \text{pgm} + \phi * \text{A} - \delta * \rho * \text{A} - \text{m};$

$\overline{\text{p}} = \hat{\text{p}} + \tau;$

$$\text{A}_{\text{gm}} = \frac{\text{B} - (\hat{\text{p}} + \tau)}{\gamma - \phi};$$

$$\text{A}_{\text{cgm}} = \frac{(\hat{\text{p}} + \tau) - \text{m}}{\delta * \rho};$$

$$\hat{\text{p}} = \frac{\delta * \rho * \text{B} + \text{m} * (\gamma - \phi)}{2 * (\gamma - \phi + \delta * \rho)} - \frac{\tau - \text{m}}{2};$$

$$\text{PS} = \int_0^{\text{A}_{\text{cgm}}} \pi_c \, d\text{A} + \int_{\text{A}_{\text{cgm}}}^{\text{A}_{\text{gm}}} \pi_h \, d\text{A} + \int_{\text{A}_{\text{gm}}}^{1} \pi_t \, d\text{A};$$

FullSimplify[PS]

$$\frac{1}{8}\left(4\,(2\,\text{pt} - 2\,\text{pts} + \gamma) + \frac{\tau^2}{\delta\,\rho} - \frac{(\text{B} - \text{m})\,(\text{B} + 3\,\text{m} - 4\,(\text{pgm} - \text{pt} + \text{pts}))}{\gamma + \delta\,\rho - \phi} - \frac{(-\text{B} + \text{m} + \tau)\,(3\,\text{B} + \text{m} - 4\,(\text{pgm} - \text{pt} + \text{pts}) + \tau)}{-\gamma + \phi}\right)$$

$\text{Damage} = \text{c} * \text{A}_{\text{gm}};$

$$\text{xh} = \frac{\delta * \rho * \text{B} - \tau * (\gamma - \phi + \delta * \rho)}{2 * (\gamma - \phi) * \delta * \rho};$$

$$\text{xc} = \frac{\delta * \rho * \text{B} + (\tau + \text{m}) * (\gamma - \phi + \delta * \rho)}{2 * (\gamma - \phi + \delta * \rho) * \delta * \rho};$$

$\text{TR} = \tau * \text{xh};$

$$\text{Fine} = \delta * \rho * \int_0^{\text{A}_{\text{cgm}}} \text{A} \, d\text{A};$$

General::spell : Possible spelling error: new symbol name "Fine" is similar to existing symbols {File, Find, Line}.

$\text{IR} = (\hat{\text{p}} - \text{m}) * \text{xh};$

$\text{EC} = \alpha * \delta + \beta;$

Welfare = FullSimplify[PS – EC – Damage + TR + Fine];

$\text{Lag} = \text{Welfare} + \lambda * (\text{IR} - \text{r});$

$\partial_\tau \text{Lag};$

$\partial_\lambda \text{Lag};$

sol1 = Solve[∂_λ Lag$*\lambda$ == 0, λ]

$\{\{\lambda \to 0\}\}$

$\lambda = 0;$

sol2 = Solve[∂_τ Lag$*\tau$ == 0, τ]

$$\left\{\{\tau \to 0\}, \left\{\tau \to \frac{\frac{3B}{\gamma-\phi} + \frac{2c}{\gamma-\phi} + \frac{m}{\gamma-\phi} - \frac{2pgm}{\gamma-\phi} + \frac{2pt}{\gamma-\phi} - \frac{2pts}{\gamma-\phi} + \frac{B}{\gamma+\delta\rho-\phi} - \frac{m}{\gamma+\delta\rho-\phi}}{\frac{2}{\delta\rho} + \frac{3}{\gamma-\phi}}\right\}\right\}$$

FullSimplify[sol2]

$$\left\{\{\tau \to 0\}, \left\{\tau \to \delta\rho\left(\frac{-B+m}{\gamma+\delta\rho-\phi} + \frac{2(-3B-c+m+pgm-pt+pts)}{-2\gamma-3\delta\rho+2\phi}\right)\right\}\right\}$$

Section 3.3(A): Determination of equilibrium price-quantity by the producers of traditional crops

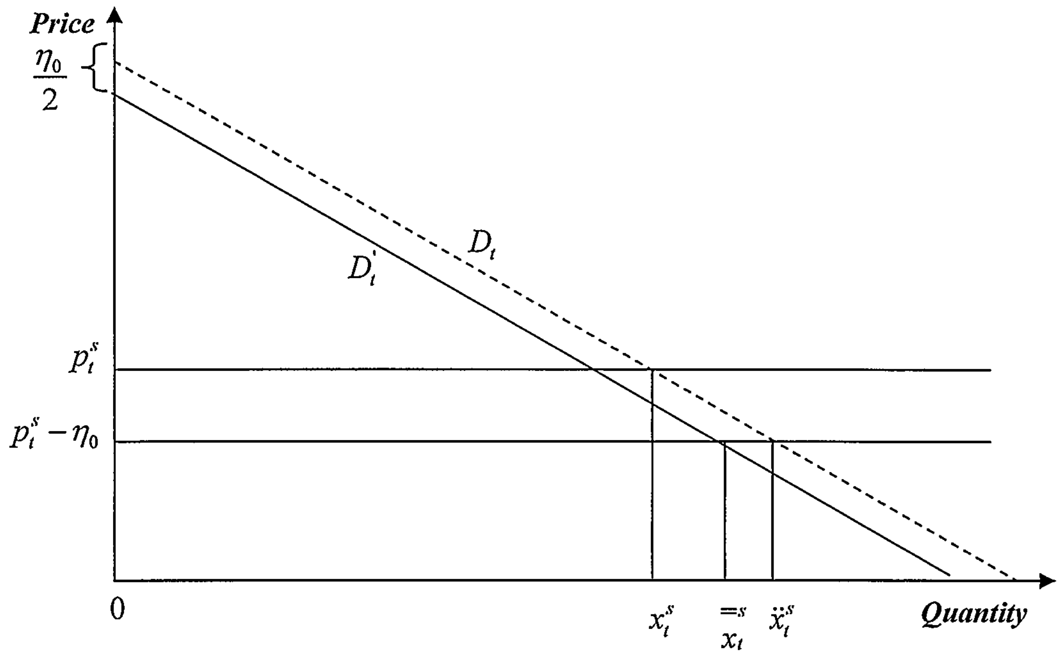

Figure A: Equilibrium price – quantity determination for the traditional seed market under perfect enforcement of IPRs

Figure A illustrates the determination of the equilibrium price-quantity combination of traditional seed by the domestic producers with subsidy under perfect enforcement of IPRs. Initially, as a result of the subsidy given to the suppliers of traditional seed, the price of seed drops from p_t^s to $p_t^s - \eta_0$ and the quantity of seed supplied increases from x_t^s to $\ddot{x}_t^s$. In response to this, the foreign innovator who is the supplier of GM seed to the domestic market, reduces its equilibrium price and therefore quantity to $\overline{\overline{p}}_{gm}^s$ and $\overline{\overline{x}}_{gm}^s$ respectively. This is shown in Figure 3.12. Finally, the demanders of traditional seed reduce their demand and quantity demanded to $\overline{\overline{x}}_t^s$, so that $\overline{\overline{x}}_t^s = (1 - \overline{\overline{x}}_{gm}^s)$, as the total seed usage sums to 100 percent. The market price of traditional seed remains fixed at $p_t^s - \eta_0$.

Section 3.3(B): Solving the innovator's problem in case (iv)

The foreign innovator maximizes profits (π) by choosing the price of GM seed ($\overset{=s}{p}_{gm}$) in the developing country market. In this case, the developing country government has introduced a subsidy (η_0) per unit of traditional seed purchased as a policy measure. The innovator's problem is given by

$$\max_{\overset{=s}{p}_{gm}} \pi = (\overset{=s}{p}_{gm} - m)\overset{=s}{x}_{gm} \qquad (A35).$$

Thus, substituting equation (3.52) which implies, $\overset{=}{A}_{gm} = \overset{=s}{x}_{gm} = \dfrac{p_{gm} - p_t + p_t^s - \eta_0 - \overset{=s}{p}_{gm}}{\gamma - \phi}$,

the innovator's problem can be re-written as

$$\max_{\overset{=s}{p}_{gm}} \quad \pi = (\overset{=s}{p}_{gm} - m)\frac{B - \overset{=s}{p}_{gm} - \eta_0}{\gamma - \phi} \qquad (A36), \text{ where } B = (p_{gm} - p_t + p_t^s).$$

The first order condition with respect to $\overset{=s}{p}_{gm}$ is

$$\frac{\partial \pi}{\partial \overset{=s}{p}_{gm}} = 0 \quad \Rightarrow \quad \frac{B - 2\overset{=s}{p}_{gm} - \eta_0}{\gamma - \phi} + \frac{m}{\gamma - \phi} = 0 \qquad (A37).$$

The second order condition is

$$\frac{\partial_2 \pi}{\partial \overset{=s}{p}_{gm}{}^2} < 0 \quad \Rightarrow \quad -\frac{2}{\gamma - \phi} < 0 \qquad (A38).$$

Solving (*A37*) for $\overset{=s}{p}_{gm}$,

$$\overset{=s}{p}_{gm} = \frac{p_{gm} - p_t + p_t^s - \eta_0 + m}{2} = \frac{B - \eta_0 + m}{2}, \text{ which is equation (3.53).}$$

Substituting the value of $\overset{=s}{p}_{gm}$ into equation (3.52),

$$\overset{=s}{x}_{gm} = \frac{p_{gm} - p_t + p_t^s - \eta_0 - m}{2(\gamma - \phi)} = \frac{B - \eta_0 - m}{2(\gamma - \phi)}, \text{ which is equation (3.54).}$$

Section 3.3(C): Derivation of producers' surplus (PS_4) and solving the government's problem in case (iv)

Government in the developing country maximizes social welfare (W_4). In this case, the developing country government has introduced a subsidy (η_0) per unit of traditional seed purchased as a policy measure. Therefore, W_4 consists of surplus earned by the domestic producers (PS_4), negative externalities of various forms arising from GM crop production (D_4^{PE}) and subsidy payments (Pa_4) made by the government. The constraint in the optimization problem would be a minimum innovator's rent implying that the innovator's rent (IR_4) would not be less than some minimum level r_4, so that the innovator finds it profitable to stay in the market

$$\begin{aligned}&\max_{\eta_0} W_4 = PS_4 - D_4^{PE} - Pa_4,\\ &subject\ \ to\ \ IR_4 > r_4\ \ (\geq 0).\end{aligned} \qquad \text{(A39)}$$

Producers' surplus is given by

$$PS_4 = \int_0^{\bar{A}_{gm}} \overline{\overline{\prod}}_{gm}^{h} dA + \int_{\overline{\overline{A}}_{gm}}^{1} \overline{\overline{\prod}}_t dA \qquad (A40).$$

Substituting equations (3.51) and (3.50) for $\overline{\overline{\prod}}_{gm}^{h}$ and $\overline{\overline{\prod}}_t$ respectively and equation (3.52) for $\overline{\overline{A}}_{gm}$,

$$PS_4 = \int_0^{\frac{B-\bar{p}_{gm}^{s}-\eta_0}{\gamma-\phi}} (p_{gm} - \overline{\overline{p}}_{gm}^{s} + \phi A)dA + \int_{\frac{B-\bar{p}_{gm}^{s}-\eta_0}{\gamma-\phi}}^{1} \{(p_t - (p_t^s - \eta_0)) + \gamma A\}dA$$

$$= p_t - p_t^s + \frac{\gamma}{2} + \eta_0 + \frac{(p_{gm} - p_t + p_t^s - m - \eta_0)^2}{8(\gamma - \phi)},$$ which is equation (3.55). The step by step derivation of PS_4 is presented at the end of this section using results from *Mathematica*.

The value of the negative external effects of new technology is given by equation (3.56), $D_4^{PE} = c \times \overset{=s}{x}_{gm}$. Total subsidy payments to the suppliers of traditional seed are $Pa_4 = \eta_0 \times (1 - \overset{=s}{x}_{gm})$, which is equation (3.57) and the innovator's rent in this case is given by equation (3.58), i.e., $IR_4 = (\overset{=s}{p}_{gm} - m) \times \overset{=s}{x}_{gm}$.

Setting up the Lagrangian of the government's problem,

$L = W_4 + \lambda(IR_4 - r_4)$, where λ is the Lagrange multiplier.

Kuhn-Tucker conditions for maximization are:

$$\left.\begin{aligned} &L'(\eta_0) \leq 0, \\ &\eta_0 \geq 0, \\ &\eta_0 L'(\eta_0) = 0 \end{aligned}\right\} \quad \text{(A41)}$$

$$\left.\begin{aligned} &(IR_4 - r_4) \leq 0, \\ &\lambda \geq 0, \\ &\lambda(IR_4 - r_4) = 0. \end{aligned}\right\} \quad \text{(A42)}$$

In this case, the optimal condition is characterized by slack constraint since $IR_4 > r_4$.

Solving Kuhn-Tucker conditions, gives

$$L'(\eta_0) = \frac{c}{2(\gamma - \phi)} - \frac{\eta_0}{2(\gamma - \phi)} - \frac{-B - m + 2p_{gm} + \eta_0}{4(\gamma - \phi)} - \frac{p_t - p_t^s + \eta_0}{2(\gamma - \phi)}$$
$$- \frac{(-B + \frac{1}{2}(B + m - \eta_0) + \eta_0)}{2(\gamma - \phi)^2}(\gamma - \phi) + \frac{B - \eta_0 + \frac{1}{2}(-B - m + \eta_0)}{2(\gamma - \phi)} \qquad (A43).$$

Now, solving for $\eta_0 L'(\eta_0) = 0$ and simplifying,

$\eta_0^* = \frac{1}{3}(p_{gm} - p_t + p_t^s + 2c - m)$, which is equation (3.59).

Calculations for PS_4:

The *Mathematica* output is presented to show detailed derivations of the analytical results. First the net returns functions are entered, shown by π_t and π_h. For notational simplicity, $\overset{=}{\Pi}_t$ is expressed as π_t, p_t^s as *pts*, η_0 as η, $\overset{=h}{\Pi}_{gm}$ as $\pi_{h,}$, $\overset{=s}{p}_{gm}$ as $\overline{p}$ and $\overset{=}{A}_{gm}$ as

A_{gm}. Similarly, to avoid complex terms, B is substituted for ($p_{gm} - p_t + p_t^s$), which is a constant. *PS* here denotes PS_4. The final expression for PS_4 can be shown to simplify to equation (3.55).

For solving the optimal subsidy function, η_0^*, the government's problem is also solved using *Mathematica*. The negative externality is denoted as the *Damage*, the total subsidy payments as *Pa*, the innovator's rent as *IR* and the social welfare function as *Welfare*. Next, differentiating and solving the Lagrangian with respect to λ and η respectively, the optimal subsidy rate simplifies to equation (3.59).

Perfect enforcement of IPRs – calculating producers' surplus (PS_4) and solving the government's problem in case (iv):

$\pi_t = pt - (pts - \eta) + \gamma * A;$

$\pi_h = pgm - \overline{p} + \phi * A;$

$A_{gm} = \dfrac{B - \eta - \overline{p}}{\gamma - \phi};$

$\overline{p} = \dfrac{B - \eta + m}{2};$

$PS = \int_0^{A_{gm}} \pi_h \, dA + \int_{A_{gm}}^{1} \pi_t \, dA;$

FullSimplify[PS]

$pt - pts + \dfrac{\gamma}{2} + \eta - \dfrac{(-B + m + \eta)(3B + m - 4(pgm - pt + pts) + \eta)}{8(-\gamma + \phi)}$

$Damage = c * x_h;$

$x_h = \dfrac{B - \eta - m}{2 * (\gamma - \phi)};$

Damage;

$Pa = \eta * (1 - x_h);$

$IR = (\overline{p} - m) * x_h;$

Welfare = PS − Damage − Pa;

Lagrange = Welfare + λ * (IR − r);

∂_λ Lagrange;

solution1 = Solve[∂_λ Lagrange * λ == 0, λ]

$\{\{\lambda \to 0\}\}$

$\lambda = 0;$

∂_η Lagrange;

solution2 = Solve[∂_η Lagrange * η == 0, η]

$\left\{\{\eta \to 0\}, \left\{\eta \to \dfrac{2B + 2c - 2pgm + 2pt - 2pts + \frac{B\gamma}{\gamma-\phi} - \frac{m\gamma}{\gamma-\phi} - \frac{B\phi}{\gamma-\phi} + \frac{m\phi}{\gamma-\phi}}{2 + \frac{\gamma}{\gamma-\phi} - \frac{\phi}{\gamma-\phi}}\right\}\right\}$

FullSimplify[solution2]

$\left\{\{\eta \to 0\}, \left\{\eta \to \dfrac{1}{3}(3B + 2c - m - 2(pgm - pt + pts))\right\}\right\}$

Section 3.4(A): Solving the innovator's problem in case (viii)

The innovator's objective is to maximize profits (π) under imperfect enforcement of IPR and determine the price of GM seed (p''^{s}_{gm}). Formally, the innovator's problem is given by

$$\max_{p''^{s}_{gm}} \pi = (p''^{s}_{gm} - m)x''^{h}_{gm} \quad \text{(A44).}$$

Subtracting $A''^{c}_{gm} = \dfrac{p''^{s}_{gm} - m}{\delta_0 \rho}$, equation (3.62) from $A''^{h}_{gm} = \dfrac{B - \eta_1 - p''^{s}_{gm}}{\gamma - \phi}$, equation (3.63), the objective function can be expressed as follows:

$$\max_{p''^{s}_{gm}} \pi = (p''^{s}_{gm} - m)\frac{\delta_0\rho(B-\eta_1) + m(\gamma-\phi) - p''^{s}_{gm}(\gamma-\phi+\delta_0\rho)}{(\gamma-\phi)\delta_0\rho} \qquad (A45).$$

The first order condition with respect to p''^{s}_{gm} is

$$\frac{\partial \pi}{\partial p''^{s}_{gm}} = 0 \quad \Rightarrow \quad \frac{(B-\eta_1)\delta_0\rho}{(\gamma-\phi)\delta_0\rho} + \frac{m(\gamma-\phi)}{(\gamma-\phi)\delta_0\rho} - \frac{2p''^{s}_{gm}(\gamma-\phi+\delta_0\rho)}{(\gamma-\phi)\delta_0\rho}$$
$$+\frac{m(\gamma-\phi+\delta_0\rho)}{(\gamma-\phi)\delta_0\rho} = 0 \qquad (A46).$$

The second order condition is

$$\frac{\partial^2 \pi}{\partial (p''^{s}_{gm})^2} < 0 \quad \Rightarrow \quad -\frac{2(\gamma-\phi+\delta_0\rho)}{(\gamma-\phi)\delta_0\rho} < 0 \qquad (A47).$$

Solving $(A46)$ for p''^{s}_{gm},

$$p''^{s}_{gm} = \frac{(p_{gm} - p_t + p^{s}_t - \eta_1)\delta_0\rho + m(\gamma-\phi)}{2(\gamma-\phi+\delta_0\rho} + \frac{m}{2}, \text{ which is equation (3.64).}$$

Substituting the value of p''^{s}_{gm} in equations (3.62) and (3.63), and making simple adjustments,

$$x''^{h}_{gm} = A''^{h}_{gm} - A''^{c}_{gm} = \frac{(p_{gm} - p_t + p^{s}_t - \eta_1 - m)}{2(\gamma-\phi)}, \text{ which is equation (3.65) and}$$

$$x''^{c}_{gm} = A''^{c}_{gm} = \frac{(p_{gm} - p_t + p^{s}_t - \eta_1 - m)}{2(\gamma-\phi+\delta_0\rho)}, \text{ which is equation (3.66).}$$

Section 3.4(B): Derivation of producers' surplus (PS_8) and solving the government's problem in case (viii)

Government in the developing country maximizes social welfare (W_8). In this case, the developing country government as a policy measure has introduced a subsidy (η_1) per unit of traditional seed purchased. Therefore, W_8 consists of surplus earned by the domestic producers (PS_8), negative externalities of various forms arising from GM crop production (D_8^{PE}), subsidy payments (Pa_8) made by the government, enforcement cost (EC) and expected revenue in the form of a penalty (F_8). The constraint in the optimization problem would be a minimum innovator's rent implying that the innovator's rent (IR_8) would not be less than some minimum level r_8, so that the innovator finds it profitable to stay in the market. The government in this case solves the following problem:

$$\begin{aligned} &\max_{\eta_1} W_8 = PS_8 - EC - D_8^{IE} - Pa_8 + F_8, \\ &subject\ \ to\ \ IR_8 > r_8\ \ (\geq 0). \end{aligned} \qquad \text{(A48)}$$

Producer's surplus is given by

$$PS_8 = \int_0^{A''^c_{gm}} \Pi^c_{gm} dA + \int_{A''^c_{gm}}^{A''^h_{gm}} \Pi''^h_{gm} dA + \int_{A''^h_{gm}}^{1} \Pi''_t dA \qquad (A49).$$

Substituting $\Pi^c_{gm} = p_{gm} + \phi A - \delta_0 \rho A - m$ from equation (3.22A), $\Pi''^h_{gm} = p_{gm} - p''^s_{gm} + \phi A$ from equation (3.61), $\Pi''_t = p_t - (p^s_t - \eta_1) + \gamma A$ from equation (3.60), $A''^c_{gm} = \dfrac{p''^s_{gm} - m}{\delta_0 \rho}$ from equation (3.62) and $A''^h_{gm} = \dfrac{B - \eta_1 - p''^s_{gm}}{\gamma - \phi}$ from equation (3.63),

$$PS_7 = \int_0^{\frac{p''^s_{gm-m}}{\delta_0 \rho}} (p_t + \phi A - \delta_0 \rho A - m) dA + \int_{\frac{p''^s_{gm-m}}{\delta_0 \rho}}^{\frac{B - \eta_1 - p''^s_{gm}}{\gamma - \phi}} (p_{gm} - \underline{p}^s_{gm} + \phi A) dA + \int_{\frac{B - \eta_1 - p''^s_{gm}}{\gamma - \phi}}^{1} (p_t - p^s_t + \gamma A) dA$$

$$= p_t - p_t^s + \frac{\gamma}{2} + \eta_1 + \frac{(-B+m+\eta_1)^2}{8(\gamma-\phi)} + \frac{3(-B+m+\eta_1)^2}{8(\gamma-\phi+\delta_0\rho)}$$, which is equation (3.67).

The step by step derivation is shown using *Mathematica* at the end of this section.

Enforcement cost of the IPRs is given by $EC = \alpha\delta_0 + \beta$, which is given by equation (3.68). The damage function is given by $D_8^{IE} = c \times (x''^{h}_{gm} + x''^{c}_{gm})$, which is equation (3.69). Total subsidy payment depends on the total non-GM seed usage, i.e., $Pa_8 = \eta_1[1-(x''^{h}_{gm} + x''^{c}_{gm})]$, which is equation (3.70). Expected revenue from penalty (F_8) is given by equation (3.71): $F_8 = \rho \int_0^{A''^{c}_{gm}} (\delta_0 A)dA$. The innovator's rent ($IR_8$) in this case is $IR_8 = (p''^{s}_{gm} - m) \times x''^{s}_{gm}$, which is equation (3.72).

Setting up the Lagrangian of the government's problem,

$L = W_8 + \lambda(IR_8 - r_8)$, where λ is the Lagrange multiplier.

Kuhn-Tucker conditions for maximization are:

$$\left.\begin{aligned} &L'(\eta_1) \le 0, \\ &\eta_1 \ge 0, \\ &\eta_1 L'(\eta_1) = 0, \end{aligned}\right\} \quad \text{(A50)}$$

and

$$\left.\begin{aligned} &(IR_8 - r_8) \le 0, \\ &\lambda \ge 0, \\ &\lambda(IR_8 - r_8) = 0. \end{aligned}\right\} \quad \text{(A51)}$$

In this case, the optimal condition is characterized by slack constraint since $IR_8 > r_8$.

Solving Kuhn-Tucker conditions, gives

$$\eta_1^* = c + (B-c-m)\left[\frac{\delta_0^2\rho^2}{4\gamma^2 + 6\gamma\delta_0\rho + 3\delta_0^2\rho^2 - 8\gamma\phi - 6\phi\delta_0\rho + 4\phi^2}\right]$$, which is equation (3.73) in section 3.4.1.

Calculations for PS_8:

Mathematica output is presented to show detailed derivations of the analytical results. First the net returns functions are entered, shown by πt, πh and πc. For notational simplicity, $\prod_t''$ is expressed as πt, p_t^s as *pts*, $\prod_{gm}''^{h}$ as πh, $p_{gm}''^{s}$ as $\overline{p}$, $\prod_{gm}^{c}$ as πc, $A_{gm}''^{h}$ as *Ah*, $A_{gm}''^{c}$ as *Ac* and η_1 is denoted by η. Similarly, to avoid complex terms, B is substituted for $(p_{gm} - p_t + p_t^s)$, which is a constant. *PS* here denotes PS_8. The final expression for PS_8 can be shown to simplify to equation (3.67).

For solving the optimal subsidy function, η_1^*, the government's problem is also solved using *Mathematica*. The negative externality is denoted as the *damage*, the enforcement cost as *EC*, the subsidy payments as *Pa*, the penalty function as *Fine*, the innovator's rent as *IR* and the social welfare function as *Welfare*. Next, differentiating and solving the Lagrangian with respect to λ and η respectively, the optimal tax rate simplifies to equation (3.73).

Imperfect enforcement of IPRs : calculating producers' surplus (PS_8) and solving the government's problem in case (viii)

$\pi t = pt - (pts - \eta) + \gamma * A;$

$\pi h = pgm - \overline{p} + \phi * A;$

General::spell1 : Possible spelling error: new symbol name "πh" is similar to existing symbol "πt".

$\pi c = pgm + \phi * A - \delta * \rho * A - m;$

General::spell : Possible spelling error: new symbol name "πc" is similar to existing symbols {πh, πt}.

$$Ac = \frac{\overline{p} - m}{\delta * \rho};$$

$$Ah = \frac{B - \eta - \overline{p}}{\gamma - \phi};$$

$$\overline{p} = \frac{(B - \eta) * \delta * \rho + m(\gamma - \phi)}{2 * (\gamma - \phi + \delta * \rho)} + \frac{m}{2};$$

$$PS = \int_0^{Ac} \pi c \, dA + \int_{Ac}^{Ah} \pi h \, dA + \int_{Ah}^{1} \pi t \, dA;$$

FullSimplify[PS]

$$\frac{1}{8}\left(4\,(2\,pt - 2\,pts + \gamma + 2\,\eta) - \frac{(-B + m + \eta)\,(3\,B + m - 4\,(pgm - pt + pts) + \eta)}{-\gamma + \phi} - \frac{(-B + m + \eta)\,(B + 3\,m - 4\,(pgm - pt + pts) + 3\,\eta)}{-\gamma - \delta\,\rho + \phi}\right)$$

$EC = \alpha * \delta + \beta;$

$Damage = c * Ah;$

$Pa = \eta * (1 - Ah);$

$$F8 = \delta * \rho * \int_0^{Ac} A \, dA;$$

$IR = (\overline{p} - m) * (Ah - Ac);$

Welfare = FullSimplify[PS − EC − Damage − Pa + F8];

Lagrange = Welfare + λ ∗ (IR − r);

∂_λ Lagrange;

sol1 = Solve[∂_λ Lagrange∗λ == 0, λ]

{{λ → 0}}

λ = 0;

∂_η Lagrange;

sol2 = Solve[∂_η Lagrange∗η == 0, η];

FullSimplify[sol2]

$$\left\{\{\eta \to 0\}, \left\{\eta \to B + c - pgm + pt - pts - \frac{(c + m - pgm + pt - pts)\,\delta^2\,\rho^2}{4\,\gamma^2 + 6\,\gamma\,\delta\,\rho + 3\,\delta^2\,\rho^2 - 8\,\gamma\,\phi - 6\,\delta\,\rho\,\phi + 4\,\phi^2}\right\}\right\}$$