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Consumer's Acceptance Towards Genetically Modified Crops and Growth of the Economy: A Theoretical Approach

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Consumer's Acceptance Towards Genetically Modified Crops and Growth of the Economy: A Theoretical Approach

Amrita Chatterjee [α] & Arpita Ghose [σ]

Abstract- This paper develops a three-sector theoretical growth model to capture the role of consumers' acceptance towards the second generation of genetically modified (GM) crops in the long run growth process of the economy. An Acceptance (towards GM crop) parameter is defined as a ratio of consumption of GM to traditional variety of food, whose growth rate is determined by growth rate of human capital. Dynamic stability of the system is ensured provided the value of acceptance parameter is within a certain range. A range of the acceptance parameter is also obtained which ensures not only the dynamic stability of the system but also ensures higher rate of growth of an economy that produces both GM and non-GM crops compared to an economy that does not produce GM crops. The empirical validation of the model through panel data analysis suggests that research and development activity in agriculture is key to the growth process of the economy as it helps to form acceptance towards new technology among consumers.

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I. Introduction

The extensive adoption of GM crops since 1996 has provided enough evidence in favor of and against Agricultural Biotechnology. There is no double about the fact that GM crops have been successful in raising production level, reducing cost and therefore been able to provide significant economic benefit at the farm level over the years (Brookes & Barfoot; 2013 and Barrows et al.; 2014). However, Mathiowetz and Jones (2016) have rightly pointed out that even if the scientific community has accepted the safety of Genetically Modified (GM) crops, the consumers are still skeptical about consumption of GM food on factors such as religion, education, socio-economic status, safety, and personal assessment of the risk–benefit ratio.

The first generation of GM crops provided improved agronomic traits such as tolerance of specific chemical herbicides and resistance to pests and diseases (James, 2003), providing direct benefits to the producer through increased profitability by increasing factor input productivity i.e. reducing factor cost (Marra et al, 2002). The A meta-analysis performed by Klumper and Qaim (2014) has showed that *"on average GM technology adoption has reduced chemical pesticide use by 37%, increased crop yields by 22%, and increased farmer profits by 68%. Yield gains and pesticide reductions are larger for insect-resistant crops than for herbicide-tolerant crops. Yield and profit gains are higher in developing countries than in developed countries." USA, Brazil, Argentina, India and Canada are the top 5 countries followed by China and Paraguay in terms of area under cultivation of GM crops. As per James (2014) farmers from developing countries of Latin* America, Asia and Africa together grew 53% of the global biotech hectares compared to industrial countries, which grew 47%, equivalent to a gap of 11 million hectares in favor of developing countries. The 5 leading biotech developing countries Brazil, Argentina, India, China, and South Africa, grew 47% of global biotech crops. However, unlike farmers, who have been benefited and quickly adopted the transgenic plants such as Bt cotton and corn and herbicide-resistant soybeans (Economic Research service, 1999), consumers have reservations about the foods produced from these crops. Introduction of the so-called first generation of GM crops met with consumer resistance on health, environmental, moral and philosophical concerns (Hobbs and Plankett, 1999; Lindner, 2000). This led to a second generation of genetic modification seeking also to improve various attributes of GM crops to provide direct benefit to the final consumer such as enhanced nutritional content, improved durability and less pesticide application (Kishore and Shewmaker. 1999), such as Golden Rice. It is a GM variety, in which beta-carotene (Vit A) synthesizing gene introduced through genetic engineering technique, that may not improve farm productivity but can improve health significantly by providing pro-vitamin A (Dawe, Robertson and Unnevehr 2002. Zimmermann and Qaim., 2004). Thus the distinct benefits provided by the GM food which are not available in non-GM food are going to be critical in forming consumers' preference for GM products (House et al, 2002).

From Smale et al (2006) we find a detailed review of literature in the context of both industrialized and non-industrialized agricultural countries which are

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either based on surveys conducted to examine consumers' concern or evaluation of consumers' willingness to pay for GM food based on stated preference method. The conclusions of the studies are mixed in non-industrialized countries with some consumers being concerned about the consumption of GM Food and some being open to it. In industrialized countries also some consumers are willing to pay price premium for non-GM food (Huffman et al., 2003) or demanding discount for consuming GM food (Grimsrud et al., 2004), though most of the studies conclude in favor of acceptance of GM crops. For more recent studies reference can be made to Nayga et al (2006), Jan et al (2008), Kimenju and Groote (2008) etc. Some studies have also focused on the welfare effect of the labeling policy or information on genetic modification on consumer welfare (Fulton and Giannakas, 2002; Huffman, 2003; Lusk et al, 2005; Carlsson et al, 2007). Later on Colson & Rousu (2013) have provided a nice review of the empirical contribution of researchers over last 15 years towards consumers' willingness to pay for GM food based on survey and experimental methods[1]. They have tried to cover a number of unresolved issues on consumer preferences. Moreover, there are few more studies which have exclusively focused on the consumers' attitude towards GM crops in developing countries; for example, Deodhar et al. (2008); Qiu et al. (2011); Mandal and Paul (2012); Kajale & Becker (2014); Kajale & Becker (2015); Kajale & Becker (2015a); Amin and Hashim (2016); Ma and Gan (2016).

Consumers seem to be more inclined towards GM crops with some beneficial attribute such as higher nutritional content or less allergic. Anderson et al (2004) has captured the essence of enhanced nutritional value of second generation of GM crop. Miles et al (2006) have shown in their survey based study on consumers that intention to purchase genetically modified food with specific benefits such as 'low-allergen food' was higher than intention to purchase an unspecified genetically modified food. Giannakas and Yiannaka (2008) have also introduced consumer-oriented second generation of GM crops in the food system to see the effect of horizontal and vertical product differentiation on heterogeneous consumers. Most recently a study by Hans et al. (2016) provides a systematic review of the literature on consumer acceptance of, and willingness-to-pay for, GM crops with enhanced vitamin levels. This study classifies the key determinants of acceptance and willingness-to-pay into five categories: socio-demographic variables, knowledge, attitudinal and behavioral determinants, and information. Labeling facility also plays an important role in forming consumers' attitude towards adoption of GM crops as that helps them to make an informed purchase (Gruère et al, 2008; Sleenhoff & Osseweijer, 2013; Vecchione et al, 2014). However, the study of existing literature shows that there is dearth of theoretical literature that tries to explain the role of consumers' acceptance towards the consumer-oriented 2nd generation of GM crops in the long run growth process of the economy. This paper attempts to analyze the same through the formulation of a growth model. Here we have avoided any complication arising out of alternative labeling regimes and segregation enforcement regulations.

A three-sector growth model has been considered with one genetically modified food crop producing sector, one traditional agricultural sector (non-GM) and a manufacturing sector. As per Curtis et al (2004) the consumers in developing countries are more inclined towards GM crops than developed countries as benefits like cost reduction, yield-increase and nutritional enhancement dominate their risk perceptions. Thus the highlighting feature of GM crop considered here is higher nutritional content (e.g. Golden Rice), thereby enticing the consumers to put positive value on it, which is captured by a positive acceptance parameter. In the demand side of the economy the role of human capital has been introduced to determine the consumers' acceptance towards GM crop. We have defined an Acceptance parameter as a ratio of consumption of GM to non-GM (traditional variety) food and growth rate of this parameter is determined by growth rate of human capital. The representative consumer maximizes the discounted flow of instantaneous utility over an infinite time horizon to get the growth rates of GM food, non-GM food and Manufacturing goods respectively. As the growth rates of GM and non-GM food depend on the acceptance parameter and also on the growth rate of human capital, we are able to put some restriction on the acceptance parameter for ensuring global dynamic stability. Moreover, we have got a range for the acceptance parameter for which the dynamic stability of the equilibrium is ensured as well as a higher rate of growth of total consumption expenditure is possible in presence of GM crop compared to an economy without producing GM crop. The rest of the present paper is organized as follows. In section two we describe the basic features of the model. The section three is concerned with analyzing the consumer's allocation problem. The steady state solution of the model is analyzed in section four. The stability properties of the model are in section five. In section six we have compared two economies, one with GM food and another without the same. The empirical validation of the theoretical model is done in section 7. Some concluding observations are made in the final section.

II. Model

The economy is composed of three sectors, two agricultural sectors, one producing a Genetically

[1] Also refer to Varzakas and Tzanidis (2016)

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Modified (GM) food product and the other producing a traditional variety and one manufacturing sector (does not use any GM product). All the three sectors use labor and the population size of each type of producer is normalized to unity. The production functions of GM and non-GM sectors are given by:

$$Y^{GM} = \mu_1 H.f(L_1, Z_1)$$

and

$$Y^{NGM} = \mu_2 H.f(L_2, Z_2)$$

Here Y^{GM} and Y^{NGM} are the agricultural output using GM seed and traditional variety of seeds respectively. L_i is the labor endowment, Z_i is the composite input other than labor and *H* is human capital. *H* represents a composite variable, which includes scientists who are engaged in research and development activities in the laboratories and the amount devoted to R & D expenditure. μ_i is the parameter which signifies the fraction of human capital going to i th sector. As different sectors require different amount of deployment of Human Capital, this parameter has different values for different sectors.

The representative producers of both GM and non-GM crop consume whatever they produce; hence they do not save or invest. That is why there is no capital accumulation from this productive activity. Hence physical capital does not enter their production function as an input. However, capital accumulation in this model originates from the manufacturing sector. The production function of the manufacturing sector is as follows,

$$Y^{M} = \mu_3 H.f(L_3, K)$$

Here Y^{M} is the output of the manufacturing sector which employs physical capital (*K*) and labor (L_3) Here μ_3 signifies the fraction of human capital going to the manufacturing sector.

In the demand side of the economy, the representative household is assumed to maximize her discounted flow of instantaneous utility over an infinite time horizon. Here we assume that each of the three types of producer consumes all the three commodities. Let the instantaneous utility function[2] be

$$U = \delta_1 \ln c_t^M + \delta_2 \ln c_t^{GM} + \delta_3 \ln c_t^{NGM} \qquad (1)$$

where c_t^M, c_t^{GM} and c_t^{NGM} respectively denote per capita consumption of manufacturing, GM food and traditional food at time t and δ_i the proportion of expenditure spent on i th good, $\forall i = 1,2,3.$ Here we define A_t which is an indicator, suitably constructed showing the degree of acceptance of the consumer towards Genetically Modified crops. A_t is the ratio in which GM and NGM food are consumed i.e.

$$A_t = \frac{c_t^{GM}}{c_t^{NGM}} > 0.$$

Intuitively, A_t is an attribute. Consumer has a perception about the acceptability of GM food which is captured by this attribute. A_t grows over time following a dynamic growth path. Now, it can be assumed that the acceptance of GM product is dependent on scientific investigation of pros and cons of the GM food and the dissemination of the knowledge to the users by the private individuals, the social planners and the personnel working in the extension division of the respective country. Here lies the role of human capital, which can be used in R&D activities to investigate the benefits available from GM food and to spread that information among the consumers. Thus the level of human capital (H) prevailing in the economy will influence the movement of acceptance parameter. As the level of human capital and knowledge increase, the probability of accepting the new GM product increases.

Thus, we assume that the movement of A_t s determined by the accumulation of human capital i.e.

$$\frac{A_t}{A_t} = \frac{\dot{H}}{H} = h \qquad (2)$$

Now, let us assume that the saving propensities of the three types of producers are s_1, s_2 and s_3. As per our model, $s_1, s_2 = 0$ and $s_3 = \dot{K}_t$. Thus the composite budget constraint of the representative consumer of the economy can be given by,

[2] This is an additively separable utility function, which is chosen keeping in mind the allocation of expenditure among the commodities.

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$$\frac{r_t.K_t}{P_t^M}+\frac{w_t.L_t}{P_t^M}=C_t^M+\frac{P_t^{NGM}}{P_t^M}.C_t^{NGM}+\frac{P_t^{GM}}{P_t^M}.C_t^{GM}+\dot{K}_t$$

$$\Rightarrow \frac{\dot{K}_t}{K_t}=\left(\frac{r_t}{P_t^M}\right)+\left(\frac{w_t/P_t^M}{K_t/L_t}\right)-\frac{C_t^M/L_t}{K_t/L_t}-P_{1t}\frac{C_t^{NGM}/L_t}{K_t/L_t}-P_{2t}\frac{C_t^{GM}/L_t}{K_t/L_t}$$

$$\Rightarrow \frac{\dot{K}_t}{K_t}=\left(\frac{r_t}{P_t^M}\right)+\frac{w_t/P_t^M}{k_t}-\frac{c_t^M}{k_t}-P_{1t}\frac{c_t^{NGM}}{k_t}-P_{2t}\frac{c_t^{GM}}{k_t}$$

where $r_t'=\frac{r_t}{P_t^M}$, $w_t'=\frac{w_t}{P_t^M}$, $r_t=$ nominal rate of return to capital, $w_t=$ nominal wage rate, n = population growth rate, $r_t'=$real return on capital and $k_t=\frac{K_t}{L_t}=$ capital per capita, $w_t'=$ real wage rate, C_t^{GM}, C_t^{NGM} and C_t^M are consumption of GM, non-GM and manufacturing commodities respectively. P_t^{GM}, P_t^{NGM} and P_t^M are respectively the prices of the three three commodities. Using price of manufacturing good as numeraire we get,

$$P_{1t}=\frac{P_t^{NGM}}{P_t^M}\text{'}P_{2t}=\frac{P_t^{GM}}{P_t^M}$$

Per capita consumption and capital stock are given by,

$$c_t^{GM}=\frac{C_t^{GM}}{L_t}, c_t^{NGM}=\frac{C_t^{NGM}}{L_t}, c_t^M=\frac{C_t^M}{L_t}, k_t=\frac{K_t}{L_t}$$

Now,

$$\frac{\dot{k}_t}{k_t}=\frac{\dot{K}_t}{K_t}-\frac{\dot{L}_t}{L_t}$$

$$\Rightarrow \frac{\dot{k}_t}{k_t}=\left(\frac{r_t}{P_t^M}\right)+\frac{w_t/P_t^M}{k_t}-\frac{c_t^M}{k_t}-P_{1t}\frac{c_t^{NGM}}{k_t}-P_{2t}\frac{c_t^{GM}}{k_t}-n$$

$$\Rightarrow \dot{k}_t=r_t'.k_t+w_t'c_t^M-P_{1t}c_t^{NGM}-P_{2t}c_t^{GM}-nk_t \quad (3)$$

$$n=\frac{\dot{L}_t}{L_t}, r_t'=\frac{r_t}{P_t^M}, w_t'=\frac{w_t}{P_t^M}$$

Thus equation (3) gives the dynamic budget constraint of the representative consumer.

III. Consumer Optimization

"The dynamic optimization problem of the representative consumer can be stated as Maximize

$$\int_0^\infty(\delta_1\ln c_t^M+\delta_2\ln c_t^{GM}+\delta_3\ln c_t^{NGM})e^{-rt}dt$$

subject to the dynamic budget constraint given by:

$$\dot{k}_t=r_t'k_t+w_t'-c_t^M-P_{1t}c_t^{NGM}-P_{2t}c_t^{GM}-nk_t$$

The consumer's problem is solved by maximizing the following current value Hamiltonian:

$$H_c=[\delta_1\ln c_t^M+\delta_2\ln(A_tc_t^{NGM})+\delta_3\ln c_t^{NGM}]+$$
$$\lambda_{kt}\,[r_t'k_t+w_t'-c_t^M-P_{1t}c_t^{NGM}-P_{2t}A_tc_t^{NGM}-nk_t]$$

Here c_t^M and c_t^{NGM} are the two control variables, k_t is the state variable whereas λ_{k_t} is the co-state variable.

The first order optimality conditions for maximization of H_c are

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$$\frac{\partial H_c}{\partial c_t^{NGM}} = 0$$
$$\frac{\partial H_c}{\partial c_t^{M}} = 0 \quad (5)$$
$$\dot{\lambda}_{k_t} = -\frac{\partial H_c}{\partial k_t} + \rho\lambda_{k_t}$$

It can be shown that equations (5) along with the transversality condition

$$\lambda_{k_t} e^{-\rho t} \to 0 \text{, as } t \to \infty \quad (6)$$

are a necessary characterization of the optimum path solving the consumer's problem. Using (5) we derive the following equations of motion:[3]

$$\frac{\dot{c}_t^{NGM}}{c_t^{NGM}} = [(r_t' - n) - \rho] - \frac{h.A_t}{P_{1t}/P_{2t} + A_t} \quad (7)$$

$$\frac{\dot{c}_t^{M}}{c_t^{M}} = [(r_t' - n) - \rho] \quad (8)$$

$$\frac{\dot{c}_t^{GM}}{c_t^{GM}} = [(r_t' - n) - \rho] - \frac{h.A_t}{P_{1t}/P_{2t} + A_t} + h \quad (9)$$

IV. Steady State

In the steady state the per capita capital stock and the level of consumption per capita of all the three goods are constant. We denote the steady state values of these variables as k^*, c_{GM}^*, c_{NGM}^* and c_M^*.

- The Modified Golden Rule

With $\frac{\dot{c}_t^{GM}}{c_t^{GM}} = \frac{\dot{c}_t^{NGM}}{c_t^{NGM}} = \frac{\dot{c}_t^{M}}{c_t^{M}} = \frac{\dot{A}_t}{A_t} = \frac{\dot{k}}{k} = 0$,

we have the modified golden rule relationship:

$$r_t' = n + \rho \quad (10)$$

This implies that the real interest rate in steady state is equal to the sum of the discount rate and growth rate of population. Thus the taste and population growth determine the real interest rate $(n+\rho)$ and technology then determines the capital stock and level of consumption consistent with that interest rate.

V. Stability Properties

We now analyze the stability properties of the system and describe the regions in the parameter space which yield unique equilibrium.

For computational convenience we redefine our utility function as,

$$U = U(c_t), \text{ where}$$
$$c_t = c_t^M + P_{1t}c_t^{NGM} + P_{2t}c_t^{GM}\ ^4 \quad (11)$$

and

$$\dot{c}_t = (r_t' - n - \rho)(c_t - P_{1t}c_t^{NGM} - P_{2t}c_t^{GM}) +$$
$$P_{1t}\left[(r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right](c_t - c_t^M - P_{2t}c_t^{GM}) +$$
$$+ P_{2t}\left[\frac{\dot{A}_t}{A_t} + (r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right](c_t - c_t^M - P_{1t}c_t^{NGM})$$

We consider the reduced system consisting of 2 differential equations described by equations (12) and (3). The system can be represented in matrix form as follows:

$$\begin{bmatrix}\dot{c}_t \\ \dot{k}\end{bmatrix} = \begin{bmatrix}(r_t' - n - \rho) + P_{1t}\left\{(r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right\} + P_{2t}\left\{(r_t' - n - \rho) + \frac{\dot{A}_t}{A_t} - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right\} & 0 \\ -1 & r_t' - n\end{bmatrix}.$$
$$\begin{bmatrix}c_t \\ k_t\end{bmatrix} + \begin{bmatrix}C_1 \\ C_2\end{bmatrix} \quad (12)$$

C_1 and C_2 consist of some terms other than the coefficients of the variables concerned and Jacobian matrix or coefficient matrix is given by

$$J = \begin{bmatrix}(r_t' - n - \rho) + P_{1t}\left\{(r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right\} + P_{2t}\left\{(r_t' - n - \rho) + \frac{\dot{A}_t}{A_t} - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right\} & 0 \\ -1 & r_t' - n\end{bmatrix}$$

[3] $\frac{\dot{c}_t^{GM}}{c_t^{GM}} = \frac{\dot{A}_t}{A_t} + \frac{\dot{c}_t^{NGM}}{c_t^{NGM}}$

[4] See the Appendix

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The necessary and sufficient conditions for dynamic stability are negative trace of the coefficient matrix [J] accompanied by positive determinant of the matrix. Since our system is linear to begin with, the elements of the coefficient matrix are a set of constants. So there is no need to evaluate them at the equilibrium. Since there is no approximation process involved, the stability inferences will no longer be local but will have global validity.

- Condition for Dynamic stability

Trace of the Jacobian matrix is given by
Trace [J] =

$$(r_t' - n - \rho) + P_{1t}\left\{(r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right\} + P_{2t}\left\{(r_t' - n - \rho) + \frac{\dot{A}_t}{A_t} - \frac{P_{2t}A_t}{P_{1t} + P_{2t}A_t}\right\} + (r_t' - n)$$

For Trace [J] <0, we need,

$$\frac{P_{1t}}{P_{2t}}\left[\frac{(r_t' - n - \rho)(1 + P_{1t} + P_{2t}) + P_{2t}h + (r_t' - n)}{P_{1t}h - (r_t' - n - \rho)(1 + P_{1t} + P_{2t}) - (r_t' - n)}\right] < A_t$$

Now, determinant of the Jacobian matrix is given by,

$$|J| = [(r_t' - n - \rho) + P_{1t}\left\{(r_t' - n - \rho) - \frac{P_{2t}A_t}{P_{1t} + P_{2t}A_t}\right\} + P_{2t}\left\{(r_t' - n - \rho) + \frac{\dot{A}_t}{A_t} - \frac{P_{2t}A_t}{P_{1t} + P_{2t}A_t}\right\}](r_t' - n)$$

For $|J| > 0$, either of the following two cases are feasible.

Case 1: Both $(r_t' - n) < 0$ and

$$(r_t' - n - \rho) + P_{1t}\left\{(r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right\} + P_{2t}\left\{(r_t' - n - \rho) + \frac{\dot{A}_t}{A_t} - \frac{P_{2t}A_t}{P_{1t} + P_{2t}A_t}\right\} < 0$$

The second condition leads us to the following condition;

$$\frac{P_{1t}}{P_{2t}}\left[\frac{(r_t' - n - \rho)(1 + P_{1t} + P_{2t}) + P_{2t}h}{P_{1t}h - (r_t' - n - \rho)(1 + P_{1t} + P_{2t})}\right] < A_t$$

Thus combining the two conditions we get:

$$\text{i} > r_t' < n \tag{13}$$

$$\text{ii} > \frac{P_{1t}}{P_{2t}}\left[\frac{(r_t' - n - \rho)(1 + P_{1t} + P_{2t}) + P_{2t}h}{P_{1t}h - (r_t' - n - \rho)(1 + P_{1t} + P_{2t})}\right] < A_t \tag{14}$$

Case 2: Both $(r_t' - n) > 0$
and

$$(r_t' - n - \rho) + P_{1t}\left\{(r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right\} + P_{2t}\left\{(r_t' - n - \rho) + \frac{\dot{A}_t}{A_t} - \frac{P_{2t}A_t}{P_{1t} + P_{2t}A_t}\right\} > 0$$

But if both of these expressions become positive, then their sum can never be negative. Since sum of these two terms is equal to the trace of the J matrix, it cannot be negative for ensuring dynamic stability. Thus if the above two conditions hold the simultaneous fulfillment of Trace [J] <0 and $|J| > 0$ will not be possible. So we discard this case.

Thus simultaneous fulfillment of (13) and (14) ensure the dynamic stability of the equilibrium which in turn put a restriction on the acceptance parameter. Therefore the consumers' acceptance parameter has an important role to play in the dynamic stability of the equilibrium. Here we note that, since GM crops are not very widely consumed all over the world, its demand will not be very high. That is why we are getting a particular range for the acceptance parameter.

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VI. Comparison of two Economies: One Producing Both GM and Non-GM Food and the Other not Producing GM Food

Let there be an economy consisting of only two sectors, one producing only traditional agricultural good and another one producing a manufacturing good. Now we define the total consumption $(c_t)_1$ of the representative consumer as:

$$(c_t)_1 = (c_t^M)_t + \tilde{P}_{1t}(c_t^{NGM})_1 \quad (15)$$

where $(c_t^M)_t$ is the per capita consumption of manufacturing good and $(c_t^{NGM})_1$ is per capita consumption of traditional agricultural commodity. $\tilde{P}_{1t}$ is the relative price of agricultural commodity with respect to the price of manufacturing good. Here we assume that all the parameters in this economy are identical with that of the economy described in the earlier sections. However, since it does not produce the GM food, there is no acceptance parameter and human capital. The consumer's dynamic optimization of the utility function

$$U = \delta_1 \ln c_t^M + \delta_2 \ln c_t^{NGM}$$

subject to the dynamic budget constraint,

$$\dot{k}_t = r_t' k_t + w_t' - c_t^M - \tilde{P}_{1t} c_t^{NGM} - nk_t$$

leads us to following growth rates of non-GM and manufacturing good:

$$\frac{(\dot{c}_t^{NGM})_1}{(c_t^{NGM})_1} = \left[(r_t' - n) - \rho\right] \quad (16)$$

$$\frac{(\dot{c}_t^{M})_1}{(c_t^{M})_1} = \left[(r_t' - n) - \rho\right]$$

Now, differentiating equation (15) we get,

$$(\dot{c}_t)_1 = (\dot{c}_t^M)_t + \tilde{P}_{1t}(\dot{c}_t^{NGM})_1 \quad (17)$$

Dividing (17) by $(\dot{c}_t)_1$ we get the growth rate of total consumption of this economy as

$$\frac{(\dot{c}_t)_1}{(c_t)_1} = \frac{(\dot{c}_t^M)_1}{(c_t)_1} + \tilde{P}_{1t}\frac{(\dot{c}_t^{NGM})_1}{(c_t)_1} \quad (18)$$

Now, differentiating equation (11) we get,

$$\dot{c}_t = \dot{c}_t^M + P_{1t}\dot{c}_t^{NGM} + P_{2t}\dot{c}_t^{GM} \quad (19)$$

Dividing (19) by the (c_t) we get the growth rate of total consumption in the economy producing all the three goods ie manufacturing good, GM food and NGM food as

$$\frac{\dot{c}_t}{c_t} = \frac{\dot{c}_t^M}{c_t} + P_{1t}\frac{\dot{c}_t^{NGM}}{c_t} + P_{2t}\frac{\dot{c}_t^{GM}}{c_t} \quad (20)$$

Now, higher growth rate of total consumption expenditure will also imply higher growth rate of the economy. The growth rate of consumption for the economy with GM food will be greater than the growth rate of consumption for the economy without GM food if,

$\frac{\dot{c}_t}{c_t} - \frac{(\dot{c}_t)_1}{(c_t)_1} > 0$, which in turn puts a restriction on the acceptance parameter:

$$\frac{P_{1t}}{P_{2t}}\left[\frac{[(r_t' - n - \rho)\{(\gamma_M - \gamma_{M_1}) + (P_{1t}\gamma_{NGM} - \tilde{P}_{1t}\gamma_{NGM_1}) + P_{2t}\gamma_{GM}\} + P_{2t}h\gamma_{GM}]}{P_{1t}h\gamma_{NGM} - (r_t' - n - \rho)\{(\gamma_M - \gamma_{M_1}) + (P_{1t}\gamma_{NGM} - \tilde{P}_{1t}\gamma_{NGM_1}) + P_{2t}\gamma_{GM}\}}\right] > A_t \quad (21)$$

where,

$$\gamma_M = \frac{c_t^M}{c_t}, \gamma_{M_1} = \frac{(c_t^M)_1}{(c_t)_1}, \gamma_{NGM} = \frac{c_t^{NGM}}{c_t}, \gamma_{NGM_1} = \frac{(c_t^{NGM})_1}{(c_t)_1}$$

and $\gamma_{GM} = \frac{c_t^{GM}}{c_t}$

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Thus combining (14) and (21) we get a range for the acceptance parameter which not only ensures dynamic stability but also implies a higher growth rate of the economy in presence of GM food as,

$$\frac{P_{1t}}{P_{2t}}\left[\frac{(r_t'-n-\rho)(1+P_{1t}+P_{2t})+P_{2t}h}{P_{1t}h-(r_t'-n-\rho)(1+P_{1t}+P_{2t})}\right]<A_t<$$

$$\frac{P_{1t}}{P_{2t}}\left[\frac{[(r_t'-n-\rho)\{(\gamma_M-\gamma_{M_1})+(P_{1t}\gamma_{NGM}-\tilde{P}_{1t}\gamma_{NGM_1})+P_{2t}\gamma_{GM}\}+P_{2t}h\gamma_{GM}]}{P_{1t}h\gamma_{NGM}-(r_t'-n-\rho)\{(\gamma_M-\gamma_{M_1})+(P_{1t}\gamma_{NGM}-\tilde{P}_{1t}\gamma_{NGM_1})+P_{2t}\gamma_{GM}\}}\right] \quad (22)$$

However, we also need condition (13) i.e. $r_t'<n$ to ensure dynamic stability. This result reinforces the importance of the acceptance parameter in this analysis.

VI. Empirical Validation

The empirical validation of role of consumer acceptance of GM food on long term growth process of the economy is done by using data on non-GM crops obtained from FAOSTAT (available in http://faostat3.fao.org) as data on GM-crops are not available. We choose to focus on the research and development activity in the area of Agriculture. If the number of agricultural researchers increases then they can disseminate their knowledge among the farmers through extension services so that the farmers can adopt the new techniques that can not only improve the yield, can also reduce the expenditure on pesticides and fertilizer which indirectly reduces the environmental footprints. Inputs from agricultural scientists, if effectively utilized, can increase GDP from agriculture and therefore can boost the overall growth of the economy as GDP from agriculture is an important component of GDP of the country.

Table 1: Dependent variable: ln(per capita GDP)

Independent variable	Model I		Model II	
	coefficient	robust SE	Coefficient	robust SE
Fertilizer	.0035542*	.0015659	.0032481**	.0017009
Fertilizer^2	-.0000115*	0.00000356	-.000011	0.00000374
Researcher	.0035587*	.001494	.0059917	.0027278
Researcher^2			-.0000114**	0.0000062
constant	6.616918*	.0613572	6.604501	.0573199

**Significant at 5%; ** significant at 10%*

We have made use of a panel data of 42 countries with 3 years of data giving rise to 126 observations. In model I we have taken log of per capita GDP of the countries as the dependent variable whereas fertilizer, square of fertilizer and number of researchers per 10 thousand farmer as the independent variable. Fertilizer[5] is expected to have a positive impact on growth of the economy up to a certain level of usage as it improves the level of production and therefore GDP from agriculture. However, overuse of fertilizer may not be able to improve production rather it will have a negative impact as was the case of Green Revolution in India. It will also harm the environment through ground and water pollution. Thus fertilizer is expected to have a positive sign whereas square of fertilizer is expected to have a negative sign. As far as researchers are concerned it is expected to have appositive impact on driving the growth process of the economy.

As we are using a panel dataset, it may suffer from the problem of Heteroscedasticity as well as autocorrelation. To correct that we have used robust variance estimates. As all the independent variables are time variant we have used Panel Fixed Effect regression. Results reported in table 1 show that in model 1 fertilizer and fertilizer square are significant at 5% level with the former having positive and later having negative sign thereby vindicating our expectations. The marginal effect of fertilizer is positive but this positive effect gets attenuated with increase in fertilizer use; though the marginal effect of fertilizer on growth of the economy evaluated at panel mean of fertilizer is positive (0.0026). That means use of fertilizer initially raises the agricultural production and beyond a certain level it has a negative impact. However, that negative effect is offset by the positive effect as the final marginal effect is positive. The variable Researcher is also having positive and significant impact on growth of the economy. In model II we have added the square of researchers as another independent variable which is having a negative sign but is significant at 10% level. If the number of researchers increases, the research and development activity in agriculture will improve which will help the farmers get proper technical assistance to boost production without harming the environment. Thus it will have a positive impact on the growth process of the economy. However, too many researchers, may be due to involvement of biotech companies, may lead to confusion and conflict thereby reducing the production. The result from Model II reinforces our expectations with a positive and significant coefficient for researchers and

[5] Nitrogen + phosphate fertilizer used in arable and permanent crop area

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negative coefficient for square of researchers. In this case also the marginal effect of the variable researcher is positive but gets reduced with increase in number of researchers though at the sample mean of the data it is having a positive value (0.0055). The marginal effect of fertilizer at the sample mean of data in this model is also positive (0.00235).

Table 2: Dependent variable: Production Index Number

Independent variable	Model III	
	coefficient	robust SE
Fertilizer	.8009666*	.2625966
Fertilizer^2	-.0020943*	.0006387
Research expenditure	5.233063**	2.666709
constant	74.49151*	8.193845

**Significant at 5%; ** significant at 10%*

In Model III we have taken Net Per Capita Production Index Number for agriculture (Agricultural PIN) as the dependent variable. As independent variable, apart from fertilizer and square of fertilizer we have taken agricultural research spending.[6] Table 2 reports robust standard errors and coefficients from Fixed Effect Panel Regression which shows that fertilizer and fertilizer square are significant with desired sign whereas Research expenditure has significant positive impact on agricultural production index. Agricultural research expenditure is supposed to encourage further development in agricultural biotechnology and thereby contributing towards improvement in agricultural production. The marginal effect of fertilizer at the sample mean is again positive (0.630445702) which implies that fertilizer usage has a positive effect on agricultural productivity though it gets reduced with overuse of fertilizer. However, fertilizer as an input in agricultural production has a positive contribution as signified by positive marginal effect. We can assume that this analysis will hold good for GM crops as well.

Thus above empirical analysis shows that research activity, both in terms of number of researchers and research expenditure, plays an important role in increasing agricultural production and therefore in the growth process of the economy. If the R & D activities can reduce environmental footprints of agricultural production and can improve yield significantly along with a cost saving mechanism, that will encourage the producers to adopt the GM technology more and more. If all these information about the positive impact of agricultural biotechnology reach the consumers apart from the producers, then obviously their acceptance towards GM food will improve. That in turn will help them consume GM food and therefore will boost the growth of the economy. In this way we can indirectly validate the findings of our theoretical model empirically.

VII. Conclusion

This paper models the environment-friendly second generation of GM crops to analyze the role of consumers' acceptance towards GM crops in the long run growth process of the economy. Here, it is assumed that the movement of the acceptance parameter is driven by the accumulation of the human capital in the economy. The dynamic optimization exercise of the representative consumer in infinite horizon framework shows that the growth rates of the GM and non-GM food depend on the acceptance parameter as well as on the growth rate of human capital. We have obtained the golden rule steady state solution where the real interest rate in steady state is equal to the sum of the discount rate and growth rate of population. Dynamic stability of the system is ensured provided certain restrictions on the acceptance parameter are fulfilled. We have also been able to get a range of the acceptance parameter which ensures not only the dynamic stability of the system but also ensures higher rate of growth of an economy that produces both GM and non-GM crops compared to an economy that does not produce GM crops. These results all the more highlight the importance of the role of consumers' acceptance of GM crops. However, there are certain limitations of this paper which can be incorporated in future. The paper does not incorporate variable like the area under GM crop in a growth maximizing or welfare maximizing framework. Moreover, different modes of financing R & D expenditure by the public sector as well as by the private sector can be incorporated. The effects of these alternative modes of financing can be compared. Another important aspect that could not be taken care of in order to keep our model simple is the issue of labeling policy.

However, we have tried to empirically validate the results of the theoretical model by using data on non-GM crops. Empirical analysis shows that research and development activity in agriculture measured by number of researchers will have a positive and significant impact on growth process of the economy. The agricultural research expenditure also has positive and significant contribution towards improvement of agricultural production. Fertilizer usage, however, will have a positive role up to a certain level and negative impact thereafter. This is in line with conventional wisdom.

[6] Share of Value Added (Agriculture, Forestry and Fishing)

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Existing literature has given a detailed description of the impact of Agricultural Biotechnology on output and prices, environment and human health touching upon the issue of intellectual property rights as well. This paper, of course, has taken recourse to the environmentally sustainable and human health enhancing positive attributes of Genetically Modified food crops, though we acknowledge that there is a school of thought which has strong reservation against the commercial production of such crops (Dona & Arvanitoyannis, 2009; Kim, 2014). Even if the environmentalists are concerned about negative effects of trasngenes used to develop genetically modified organisms, Bakshi (2003) has reviewed the literature to show that GM crops available in the market that are intended for human consumption are generally safe and consumption of them does not bring any serious health issue. Thus it is an open debate that requires scientific investigations and therefore has got much attention in the economic literature (Domingo and Bordonaba; 2011; Delaney, 2015). Thus prolonged application on animals and clinical trials are required before the release of GM crops into the environment. Moreover, the approval of GM foods for commercial use by the Government authorities and formulation of relevant policies should be based on strict scientific assessments of benefits and risks of these crops, rather than being influenced by the campaigning of the so called public interest groups. Thus the acceptance of GM product is dependent on scientific investigation of pros and cons of the GM food and the dissemination of the knowledge to the users by the private individuals, the social planners and the personnel working in the extension division of the respective country. It makes the role of human capital all the more significant.

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Appendix

1. Consumer's Optimization

The current value Hamiltonian is given by:

$$H_c = [\delta_1 \ln c_t^M + \delta_2 \ln\left(A_t c_t^{NGM}\right) + \delta_3 \ln c_t^{NGM}] + \lambda_{kt}\,[r_t^{/} k_t + w_t^{/} - c_t^M - P_{1t} c_t^{NGM} - P_{2t} A_t c_t^{NGM} - n k_t] \quad \text{(A.1)}$$

Applying the maximum principle to the current value Hamiltonian we obtain:
The first order optimality conditions for maximization of H_c are

$$\frac{\partial H_c}{\partial c_t^{NGM}} = 0 \Rightarrow \lambda_{kt} = \frac{\delta_1 + \delta_2}{c_t^{NGM}\left(P_{1t} + A_t P_{2t}\right)} \quad \text{(A.2)}$$

$$\frac{\partial H_c}{\partial c_t^{M}} = 0 \Rightarrow \lambda_{kt} = \frac{\delta_1}{c_t^{M}} \quad \text{(A.3)}$$

$$\dot{\lambda}_{k_t} = -\frac{\partial H_c}{\partial k_t} + \rho \lambda_{k_t} \quad \text{(A.4)}$$

From (A.2)

$$\dot{\lambda}_{kt} = -\frac{(\delta_1 + \delta_2)\dot{c}_t^{NGM}}{(c_t^{NGM})^2\left(P_{1t} + A_t P_{2t}\right)} - \frac{(\delta_1 + \delta_2) P_{2t} \dot{A}_t}{c_t^{NGM}\left(P_{1t} + A_t P_{2t}\right)^2} \quad \text{(A.5)}$$

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$$\frac{\partial H_c}{\partial k_t} = \lambda_{k_t}.(r_t' - n) = \frac{\delta_1 + \delta_2}{c_t^{NGM}(P_{1t} + A_t P_{2t})}.(r_t' - n) \quad \text{(A.6)}$$

From (A.4) and (A.6) we get,

$$\dot{\lambda}_{k_t} = \frac{\delta_1 + \delta_2}{c_t^{NGM}(P_{1t} + A_t P_{2t})}.\rho - \frac{\delta_1 + \delta_2}{c_t^{NGM}(P_{1t} + A_t P_{2t})}.(r_t' - n) \quad \text{(A.7)}$$

Equating (A.5) and (A.7) we get,

$$-\frac{(\delta_1 + \delta_2)\dot{c}_t^{NGM}}{(c_t^{NGM})^2(P_{1t} + A_t P_{2t})} - \frac{(\delta_1 + \delta_2)P_{2t}\dot{A}_t}{c_t^{NGM}(P_{1t} + A_t P_{2t})^2} = \frac{\delta_1 + \delta_2}{c_t^{NGM}(P_{1t} + A_t P_{2t})}.\rho -$$

$$\frac{\delta_1 + \delta_2}{c_t^{NGM}(P_{1t} + A_t P_{2t})}.(r_t' - n) \quad \text{(A.8)}$$

where, $\frac{\dot{A}_t}{A_t} = \frac{\dot{H}}{H} = h$

From (A.3) we get,

$$\dot{\lambda}_{k_t} = -\frac{\delta_1.\dot{c}_t^M}{c_t^{M\,2}} \quad \text{(A.9)}$$

Since, $\frac{\partial H_c}{\partial k_t} = \lambda_{k_t}.(r_t' - n) = (r_t' - n).\frac{\delta_1}{c_t^M}$ (A.10)

From (A.4) we get,

$$\dot{\lambda}_{k_t} = -(r_t' - n)\frac{\delta_1}{c_t^M} + \rho.\frac{\delta_1}{c_t^M} \quad \text{(A.11)}$$

Equating (A.9) and (A.10) we get,

$$-\frac{\delta_1.\dot{c}_t^M}{c_t^{M\,2}} = -(r_t' - n)\frac{\delta_1}{c_t^M} + \rho.\frac{\delta_1}{c_t^M}$$

$$\Rightarrow \frac{\dot{c}_t^M}{c_t^M} = [(r_t' - n) - \rho] \quad \text{(A.12)}$$

$$\frac{\dot{c}_t^{GM}}{c_t^{GM}} = \frac{\dot{A}_t}{A_t} + \frac{\dot{c}_t^{NGM}}{c_t^{NGM}} \Rightarrow \frac{\dot{c}_t^{GM}}{c_t^{GM}} = \frac{\dot{A}_t}{A_t} + [(r_t' - n) - \rho] - \frac{h.A_t}{P_{1t}/P_{2t} + A_t} \quad \text{(A.13)}$$

Now, we define $c_t = c_t^M + P_{1t}c_t^{NGM} + P_{2t}c_t^{GM}$

Differentiating we get,

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$$\dot{c}_t = \dot{c}_t^M + P_{1t}\dot{c}_t^{NGM} + P_{2t}\dot{c}_t^{GM}$$

$$\Rightarrow \dot{c}_t = (r_t' - n - \rho).c_t^M + P_{1t}\left[(r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right]c_t^{NGM} +$$

$$+ P_{2t}\left[\frac{\dot{A}_t}{A_t} + (r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right]c_t^{GM}$$

$$\Rightarrow \dot{c}_t = (r_t' - n - \rho)(c_t - P_{1t}c_t^{NGM} - P_{2t}c_t^{GM}) +$$

$$P_{1t}\left[(r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right](c_t - c_t^M - P_{2t}c_t^{GM}) \quad \text{(A.14)}$$

$$+ P_{2t}\left[\frac{\dot{A}_t}{A_t} + (r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right](c_t - c_t^M - P_{1t}c_t^{NGM})$$

Derivation of the condition for dynamic stability:
We need trace of Jacobian matrix to be negative where the matrix is,

$$J = \begin{bmatrix} (r_t' - n - \rho) + P_{1t}\left\{(r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right\} + P_{2t}\left\{(r_t' - n - \rho) + \frac{\dot{A}_t}{A_t} - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right\} & 0 \\ -1 & r_t' - n \end{bmatrix}$$

Now, Trace of

$$|J| = [(r_t' - n - \rho) + P_{1t}\left\{(r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right\} +$$

$$P_{2t}\left\{(r_t' - n - \rho) + \frac{\dot{A}_t}{A_t} - \frac{P_{2t}A_t}{P_{1t} + P_{2t}A_t}\right\}](r_t' - n) \quad \text{(A.15)}$$

After algebric manipulation of (A.15) we get, trace of J matrix will be negative if,

$$(r_t' - n - \rho)(1 + P_{1t} + P_{2t}) - \frac{P_{2t}.\dot{A}_t}{P_{1t} + P_{2t}A_t}[P_{1t} + P_{2t}] + P_{2t}\frac{\dot{A}_t}{A_t} + (r_t' - n) < 0$$

$$\Rightarrow (r_t' - n - \rho)(1 + P_{1t} + P_{2t}) + P_{2t}\frac{\dot{A}_t}{A_t} + (r_t' - n) < \frac{P_{2t}.\dot{A}_t}{P_{1t} + P_{2t}A_t}[P_{1t} + P_{2t}]$$

$$\Rightarrow (r_t' - n - \rho)(1 + P_{1t} + P_{2t}) + P_{2t}.h + (r_t' - n) < \frac{P_{2t}.A_t.h}{P_{1t} + P_{2t}A_t}[P_{1t} + P_{2t}]$$

After some more algebric manipulation we get,

$$\frac{P_{1t}}{P_{2t}}\left[\frac{(r_t' - n - \rho)(1 + P_{1t} + P_{2t}) + P_{2t}h + (r_t' - n)}{P_{1t}h - (r_t' - n - \rho)(1 + P_{1t} + P_{2t}) - (r_t' - n)}\right] < A_t$$

Now, determinant of the Jacobian matrix is given by,

$$|J| = [(r_t' - n - \rho) + P_{1t}\left\{(r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right\} + P_{2t}\left\{(r_t' - n - \rho) + \frac{\dot{A}_t}{A_t} - \frac{P_{2t}A_t}{P_{1t} + P_{2t}A_t}\right\}](r_t' - n)$$

For $|J| > 0$, either of the following two cases are feasible.

Case 1: Both $(r_t' - n) < 0$ and

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$$(r_t' - n - \rho) + P_{1t}\left\{(r_t' - n - \rho) - \frac{P_{2t}\dot{A}_t}{P_{1t} + P_{2t}A_t}\right\} + P_{2t}\left\{(r_t' - n - \rho) + \frac{\dot{A}_t}{A_t} - \frac{P_{2t}A_t}{P_{1t} + P_{2t}A_t}\right\} < 0$$

$$\Rightarrow (r_t' - n - \rho)(1 + P_{1t} + P_{2t}) + P_{2t}.h < \frac{P_{2t}.\dot{A}_t}{P_{1t} + P_{2t}A_t}[P_{1t} + P_{2t}]$$

$$\Rightarrow \frac{P_{1t} + P_{2t}.A_t}{P_{2t}.h.A_t} < \frac{P_{1t} + P_{2t}}{(r_t' - n - \rho)(1 + P_{1t} + P_{2t}) + P_{2t}.h}$$

After some simplifications we get,

$$\frac{P_{1t}}{P_{2t}}\left[\frac{(r_t' - n - \rho)(1 + P_{1t} + P_{2t}) + P_{2t}h}{P_{1t}h - (r_t' - n - \rho)(1 + P_{1t} + P_{2t})}\right] < A_t$$

2. Comparison of two economies:

$$\frac{(\dot{c}_t)}{c_t} - \frac{\dot{c}_{t\ 1}}{(c_t)_1} > 0$$

Using the set of equations from (15) to (20) we get,

$$\left[\frac{\dot{c}_t^M}{c_t} - \frac{(\dot{c}_t^M)_1}{(c_t)_1}\right] + \left[P_{1t}.\frac{\dot{c}_t^{NGM}}{c_t} - \tilde{P}_{1t}.\frac{(\dot{c}_t^{NGM})_1}{(c_t)_1}\right] + P_{2t}\frac{\dot{c}_t^{GM}}{c_t} > 0$$

$$\Rightarrow (r_t' - n - \rho)\left[\frac{c_t^M}{c_t} - \frac{(c_t^M)_1}{(c_t)_1}\right] +$$

$$\left[P_{1t}\left\{(r_t' - n - \rho) - \frac{P_{2t}.\dot{A}_t}{P_{1t} + P_{2t}.A_t}\right\}.\frac{c_t^{NGM}}{c_t} - \tilde{P}_{1t}(r_t' - n - \rho).\frac{(c_t^{NGM})_1}{(c_t)_1}\right] + P_{2t}.\frac{\dot{c}_t^{GM}}{c_t^{GM}}.\frac{c_t^{GM}}{c_t} > 0$$

$$\Rightarrow (r_t' - n - \rho)[\gamma_M - \gamma_{M_1}] + \left[P_{1t}\left\{(r_t' - n - \rho) - \frac{P_{2t}.A_t.h}{P_{1t} + P_{2t}.A_t}\right\}.\gamma_{NGM} - \tilde{P}_{1t}(r_t' - n - \rho).\gamma_{NGM_1}\right]$$
$$+ P_{2t}\left[h + (r_t' - n - \rho) - \frac{P_{2t}.h.A_t}{P_{1t} + P_{2t}A_t}\right].\gamma_{GM} > 0$$

After certain algebric manipulation we get,

$$\frac{P_{1t}}{P_{2t}}\left[\frac{[(r_t' - n - \rho)\{(\gamma_M - \gamma_{M_1}) + (P_{1t}\gamma_{NGM} - \tilde{P}_{1t}\gamma_{NGM_1}) + P_{2t}\gamma_{GM}\} + P_{2t}h\gamma_{GM}]}{P_{1t}h\gamma_{NGM} - (r_t' - n - \rho)\{(\gamma_M - \gamma_{M_1}) + (P_{1t}\gamma_{NGM} - \tilde{P}_{1t}\gamma_{NGM_1}) + P_{2t}\gamma_{GM}\}}\right] > A_t$$

where,

$$\gamma_M = \frac{c_t^M}{c_t}, \gamma_{M_1} = \frac{(c_t^M)_1}{(c_t)_1}, \gamma_{NGM} = \frac{c_t^{NGM}}{c_t}, \gamma_{NGM_1} = \frac{(c_t^{NGM})_1}{(c_t)_1} \text{ and } \gamma_{GM} = \frac{c_t^{GM}}{c_t}$$

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