



## *Institute Of African Economic Studies*

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IAES Working Paper Serious NO. A03/2011

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**IAES Working Paper**

**Abstract**

*This paper attempts to model the dynamic ideas of Gebre-Hiwot using a dynamic programming approach of mathematical modeling. We modeled the dynamics of conflict and unequal exchange in relation to labour supply, productive land and output (GDP). Using the Euler equation first order condition, we have derived the relationship between productive land and unequal exchange as well as labour supply and conflict with their implication to output (GDP) from the bellman equation. At the optimum, labour supply at any time  $t$  is negatively related to the previous period political instability (conflict) with further negative effect on GDP. Similarly, productive land at any time  $t$  is also negatively determined by the previous period decision to trade with unequal trading partner in the international market with negative implications for output growth. We noted that this early 20<sup>th</sup> century Ethiopian problems are still a problem in 21<sup>st</sup> century Ethiopia as well as other developing countries. A solution to that problem requires an analytical clarity in the first place. That is what we have attempted to do in this paper.*

**Key words:** Conflict, political instability, unequal exchange, Ethiopian/African Development, Gebre-Hiwot Baykedagne..

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## 1. Introduction

Gebre-Hiwot Baykedagn was born in 1886 in the village of May Masha in the district of Adwa, Tigray region of northern Ethiopia (see Alemayehu,2002; Ayele, 1981 and Baharu,2002).The early 1890s were a period of exceptional turbulence in Tigray where, according to Baharu (2002), the political disintegration and psychological void created by the death of Emperor Yohannes, the ravages of one of the longest and most devastating famines of the country had ever known, and the depredation that attended Emperor Menilik's campaign of 1890 to assert his new imperial authority all combined to produce great instability (Alemayehu,2002; Baharu, 2002). It was in this circumstances that he fled with some of his companion to Eritrea at the age of seven and joined the Swedish mission school at Menkullu, on the main land off Massawa (see Abdulhakim,1997; Alemayehu, 2002; 2008a, Baharu, 2002; Sosina, 1999 and Tenkir, 1995).

According to Baharu (2002), a trip to port of Massawa that Gebre-Hiwot subsequently made with his friends was to change the course of his life. Along with them, he got permission from the captain of a German ship docked there to look around. He was curious to know how the ship is working and lost in the process and the ship left having him onboard and unnoticed. On arrival at the destination, the captain entrusted him to the rich Austrian family, which adopted him (see Alemayehu, 2002; 2008; Bahru, 2002; Ayele, 1981 ). Subsequently, he learned the German language and went on to study medicine at Berlin University (see Alemayehu, 2002; 2008a; Ayele, 1981; Baharu, 2002 and Sosina 1999).Having completed his studies in Germany, he returned to Ethiopia, learned the Amharic language (reportedly just in 7 months) in which language he wrote his two classicbooks and reportedly made the private secretary and interpreter to emperor Menilik (see Alemayehu,2002, 2008a; and Baharu,2002). In November 1909, he chose to exile himself in the British colony of Sudan, apparently having difficulties with the powerful wife of the emperor - empress Taytu (Abdulhakim,1997;Alemayehu,2002; 2008; Ayele, 1981 and Baharu,2002). Having returned from the Sudan, he wrote his first book entitled, *Atse Menilik na Ethiopia (ገገ ምንጊክና ኢትዮጵያ)* in Asmara, which literally can be translated as Emperor Menilik and Ethiopia (see Ayele, 1981 and Baharu, 2002). He returned from the Sudan being critically ill. He recovered after being hospitalized at Massawa and subsequently wrote his second treatise on *Mengiest Na Yehizbe Astedader (መንግስትና የህዝብ አስተዳደር)* meaning government and

governance/ or government and public administration or more appropriately it can be translated as ‘the political economy of development’ (see Abdulhakim, 1997; Alemayehu, 2002, 2008a; and Baharu, 2002).

In his work titled *Mengiist Na Yehizbe Astedader Gebre-Hiwot* has raised various issues, and the book is a pioneering work on development Economics, political economy of Ethiopia and Trade and environment studies. Ethiopian historian characterized him as a reformist intellectual of the early twentieth century Ethiopia (see Baharu, 1991, 1995 and 2002); Ethiopian economists take him as a pioneer development economist (see Abdulhakim, 1997; Alemayehu, 2002, 2008a, and 2011a; Ayele, 1981; Sosina, 1999 and Tenkir, 1995) and environmental students of Ethiopia viewed him as the first Ethiopian thinker on environment and development (see Emmanuel, 2004).

Notwithstanding these, one of the short comings of the economic studies to date is to cast his dynamic ideas in a static modeling framework. However, Gebre-Hiwot’s ideas are essentially dynamic. For instance, his discussion on conflict and unequal exchange are essentially dynamic where time does matter yet not modeled in dynamic terms. This paper attempts to bridge this gap in the literature on Gebre-Hiwot.

## 2. The theory

Gebre-Hiwot believed that Ethiopian development is constrained by two factors: internal, related to conflict and its impact and external, which is related to unequal exchange (see Alemayehu, 2002 and 2008a). An examination of these broad factors shows a number of dynamic issues incorporated in the analysis to which we resort in the rest of this paper. It has to be noted from the outset that our focus on Geber-Hiwot is not simply for historical curiosity, legitimate that as it is. Our interest emanates from the belief that it also captures the late 20<sup>th</sup> and early 21<sup>st</sup> century problems of Ethiopian development in analytically neat manner and hence its relevance now<sup>1</sup> (see Alemayehu 2008b).

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<sup>1</sup> The civil war in Ethiopia that lasted until 1991 ( and still not fully resolved); the nature of Ethiopia’s external trade today where Ethiopia’s exports are basically primary commodities (Over 95%) while its imports being manufactured goods; shows the similarity between the current and the early 20<sup>th</sup> century development problems of the country..

## 2.1 The Internal Constraint

### Conflict and Political instability

For Gebre-Hiwot, conflict between two different ethnic groups (ቆሮዎች) at any time reduces the amount of total labour supply for use in cultivable productive land of the country in the current and subsequent periods. This is because conflict entails destruction, including by death, of available labour force. It also leaves productive land uncultivated during the period of conflict ( see Gebre-Hiwot, 1924: 32, Tenkir, 1995:72). This further results in land degradation for in that particular period productivity of the land, according to Gebre-Hiwot, is a positive function of the amount of labour applied on it.<sup>2</sup> The combined effect is to reduce total agricultural output of the economy (Gebre-Hiwot, 1924: 33, Tenkir<sup>3</sup> 1995:73).

## 2.2 The External Constraints

### Unequal exchange

Gebre-Hiwoto noted that whenever developing countries (people with low level of skill and technology – Ethiopia for him) trade with the developed one (people with high level of skill and technology – Europe for him), they are bound to face the following. First, they face trade deficit since the gap between the import and export price of the two trading partners is large<sup>4</sup>. Consequently, the productivity of land for the less developed country will diminish – (ie there will be exhaustion of the land resource -land degradation included), since the unequal exchange implies providing more of the resources for less. In addition the meager earning from international trade by the less developed country would not allow farmers to maintain the productivity of the degraded (exhausted or used up) land and its resources, which reduces agricultural output. Second, low agricultural output in turn brings a reduction in the total

<sup>2</sup> On page 32-34 Gebre-Hiwot has clearly shown how conflict leads to reduction of supply of productive labour and a fall in productivity of land owing to conflict. He has illustrated that using Ethiopian history on page 35-42 (see Tenkir from page 17-25 too). Similarly on page 69-71 (see Tenkir from page 44-47 too) Gebre-Hiwot has shown how unequal exchange leads to exhaustion of all resources (in particular land) in the relatively less developed trading partner country. In addition, the adverse consequence of perennial conflicts could be also in terms of. Stagnation and risk for accumulation which is clearly stated in Gebre-Hiwot's book. Understandably, the peasant's response was being risk averse which is inimical for expanded production. We would like to thank one of the referees of the journal to bring this out explicitly to our attention.

<sup>3</sup> A reference to Tenkir, 1995, throughout shows the relevant page(s) for English readers of the accompanied citation to Gebre-Hiwot's Amharic book. Tenkir translated this book in 1995 and referred here as Tenkir (1995).

<sup>4</sup> For Gebre-Hiwot, the price (value) of a certain product is determined by the level of technological advancement of the country and hence the labour applied on it. Hence, the lower the level of technological advancement of the country, the lower the price of its product in the international market since its demand in the technologically advanced country is less. Besides, he describes technological advancement of the country in terms of the type of labour (skill or unskilled) used in its products. The price gap could have been offset by the large quantity supplied had there not been export supply constraint due to conflict in the early 20<sup>th</sup> century that he stressed. Moreover import demand for primary commodities is income inelastic and exports of Ethiopian were and still are supply and income inelastic. This is what in the literature called the Marshall-Lerner Condition (see Alemayehu 2011b)

labour supply since it would be difficult, according to Gebre-Hiwot, for the peasant to stay in a place where the produce of the land is significantly diminished and hence they will prefer to migrate out of the country<sup>5</sup> (Gebre-Hiwot, 1924: 70, Tenkir, 1995:107).

### 3. The Static Model

Gebre-Hiwot classified total output into agricultural and non- agricultural output. However, in his model non-agricultural output takes a small fraction of the total output. Hence, emphasizing the agricultural sector, we can represent the sector's output as a function of productive land and labour supply as given by equation 1;

$$Y_a = f(L_p, L_s) \dots\dots\dots (1)$$

Where,  $Y_a$  is agricultural output,  $L_p$  is productive land and  $L_s$  is labour supply.

For him, assuming equal volume of trade, productive land is determined by the degree of unequal exchange which is measured by the ratio of the type of labour employed in producing tradable goods between the two trading partner and labour supply. This is given as:

$$L_p = f(UT, L_s) \dots\dots\dots (2)$$

Where, UT is an indicator of unequal exchange

On the other hand, for Gebre-Hiwot labour supply is determined by the level of conflict (political instability), which results in a fall in labour supply due to death from war as well as the decline in availability of productive land (see Gebre-Hiwot, 1924:33, Tenkir,1995:73). In the absence of productive land, the total labour supply will decline since the producers will migrate to other countries where they could get more productive and cultivable land ( Gebre-Hiwot, 1924: 70, Tenkir 1995,107). Hence, algebraically, Gebre-Hiwot's labour supply equation can be written as:

$$L_s = f(C, L_p) \dots\dots\dots(3)$$

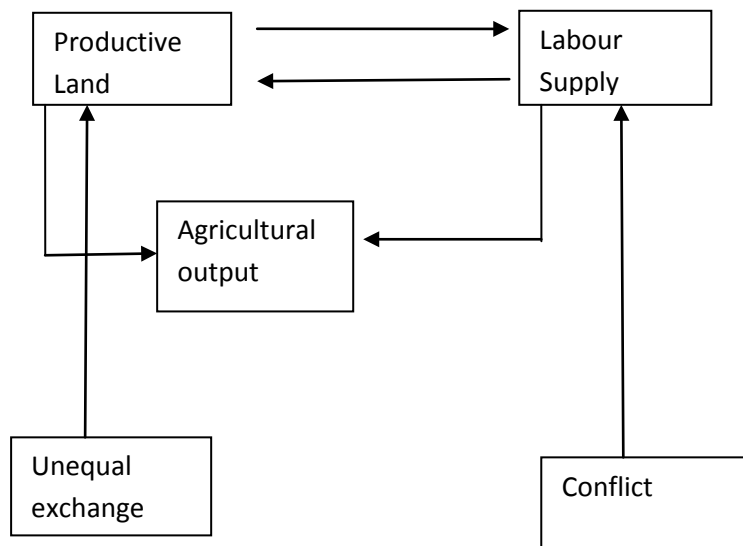
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<sup>5</sup> Here they will either join the urban unemployment, the informal sector or migrate out of the country, Ethiopia. In all cases the supply of labour in agriculture (and hence output) will decline.

Where  $C$ , is the degree of conflict (political instability).

In sum, conflict reduces the amount of labour supply that could be used in the productive land, which further reduces the productivity of cultivable land and hence the total agricultural output in the economy. Similarly, unequal exchange results in exhaustion of the land resource (land degradation included), which reduces total labour supply since land degradation results in a reduction of agricultural output that will sustain the producers as it is the mainstay of the the economy.

Diagrammatically, their relationship summarized as follows;



Thus, in Gebre-Hiwot model, productive land is affected by engagement in unequal exchange whereas labour supply is affected by conflict (political instability) directly as well indirectly. The latter in turun affect the availability of productive land.

Moreover, in his model the composition (skilled and unskilled) of labour supply is a function of the level of public spending on human capital formation, which transforms the unskilled labour supply into a skilled one.

#### 4. Transitional dynamics

As we have observed in the previous subsection, productive land is determined by labour supply and unequal exchange. Labour supply is in turn also determined by conflict/political instability and the level of (public) spending on human capital formation.

Hence, the state of transition of productive land from time  $t$  to time  $t+1$  in reduced form is a function of conflict and unequal exchange of a country with its trading partner.

Assuming  $\varphi \in (0,1)$  captures the proportion of productive land resource exhausted (or degraded) at time  $t$  as a result of labour shortage which in turn is due to conflict,  $\lambda \in (0,1)$  represents the proportion of productive land degraded as a result of inter-regional trade within a country and  $\delta \in (0,1)$  represents the proportion of land degraded at time  $t$  due to low return from international trade owing to unequal exchange, the state of productive land at time  $t+1$  can be written as the difference between productive land at time  $t$  and the proportion of productive land degraded as a result of conflict instigated low labour force supply, inter-regional trade within a country and unequal exchange in international trade and given by<sup>6</sup>;

$$\begin{aligned}
 L_{p,t+1} &= L_{p,t} - \varphi L_{p,t} - \delta L_{p,t} - \lambda L_{p,t} \\
 &= (1 - \varphi - \delta - \lambda)L_{p,t} \\
 &= (1 - \varphi - \delta - \lambda)L_{p,t} \dots\dots\dots (4)
 \end{aligned}$$

For Gebre-Hiwot, if land is left abandoned for a long time, cost of clearing and related costs of land development are higher than the gain in fertility that would be obtained from fallowing. The shortage of labour here is owing to the sustained conflict, which will make it difficult to restore the land to its former level of productivity ( see Gebre-Hiwot, 1924: 33, Tenkir ,1995: 73) . Gebre-Hiwot also classified total labour supply into skilled and unskilled, as we noted above. Therefore, total labour supply at any period is given by the sum of skilled and unskilled labour supply represented as:

$$L_{s,t} = L_{sk,t} + L_{usk,t} \dots\dots\dots (5) t$$

Where,  $L_{sk,t}$  and  $L_{usk,t}$  represents skilled and unskilled labour supply at time  $t$  respectively.

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<sup>6</sup>Since conflict and unequal exchange affect productive land negatively, the transition of productive land from time  $t$  to time  $t+1$  is always represented by degradation (exhaustion of resources).



Each time a proportion of  $\theta \in (0,1)$  skilled labour force supply is lost (destroyed) as a result of conflict; those who survived  $1-\theta$  do transit to period  $t +1$ . Likewise, each time a proportion of  $\gamma \in (0,1)$  unskilled labour force supply is lost owing to conflict and the remaining  $1-\gamma$  of the unskilled labour force could survive and transit to period  $t+1$ .

Moreover, out of  $1-\gamma$  unskilled labour force  $\rho \in (0,1)$  a fraction of them becomes skilled due to public spending on human capital formation. Hence, skilled labour force in period  $t+1$  is given by the sum of those survived skilled labourers at time  $t$  and those survived unskilled labourers who became skilled as a result of spending on human capital formation at time  $t$ , represented by;

$$L_{sk,t+1} = (1-\theta)L_{sk,t} + \rho(1-\gamma)L_{usk,t} \dots\dots\dots (6)$$

Similarly, unskilled labour force supply in period  $t+1$  is given by the survived unskilled labour force at time  $t$ , represented by;

$$L_{usk,t+1} = (1-\gamma)L_{usk,t} \dots\dots\dots (7)$$

Substituting equations (6) and (7) into equation (5), labour supply at time  $t+1$  can be rewritten as;

$$L_{s,t+1} = (1-\theta)L_{sk,t} + (1-\gamma)(\rho L_{usk,t} + L_{usk,t}) \dots (8)$$

In sum, from the static model and the transitional dynamics equations, the state of productive land at time  $t+1$  is controlled by the time  $t$  productive land, conflict and the degree of an equal exchange . Likewise, the state of labour force supply at time  $t+1$  is controlled by the time  $t$  labour supply, state of conflict and public spending on human capital formation. Hence, in Gebre-Hiwot model labour supply and productive land are the state variables whereas conflict and the decision to trade with unequal trading partner (unequal exchange) are the control variables. It is imperative to note in passing that the former control variable is within the reach of the Ethiopian government while the latter is not. This is relevant for all African countries today where some policy options are within their reach while other are not. Coming to our formulation, in the next subsection, using the dynamic programming approach, we will model the dynamic ideas of Gebre-Hiwot in a dynamic mathematical framework.

### 5. The Dynamics of the model

We have assumed Gebre-Hiwot’s ideal representative government is an infinitely lived agent, whose objective is to find the optimum level of productive land and labour supply given the control sequences of  $\{C_t, UT_t\}_{t=0}^{\infty}$  which maximize its entire life time utility which is given by:

$$\max_{\{C, UT\}_{t=0}^{\infty}} E_o \left[ \sum_{t=0}^{\infty} \beta^t U(L_{s,t}, L_{p,t}, UT_t, C_t) \right] \dots (9)$$

Subject to the state of transitions of labour supply and productive land given by;

$$L_{s,t+1} = f(L_{s,t}, C_t) \dots (10)$$

$$L_{p,t+1} = f(L_{p,t}, UT_t) \dots (11)$$

Where  $\beta \in (0,1)$  denotes the discount factor and E denotes the sign of expectation.

To find the optimal level of the state variables as a function of the control variable, we first define the value function V:

$$V_o \equiv \max_{\{C, UT\}_{t=0}^{\infty}} E_o \left[ \sum_{t=0}^{\infty} \beta^t U(L_{s,t}, L_{p,t}, UT_t, C_t) \right] \dots (12)$$

Equation (12) can be transformed to

$$V_o \equiv \max_{\{C, UT\}_{t=1}^{\infty}} \left\{ \left[ U(L_{s,o}, L_{p,o}, UT_o, C_o) \right] + \beta V_1 \right\} \dots (13)$$

Where,

$$V_1 \equiv \max_{\{C, UT\}_{t=1}^{\infty}} E_1 \left[ \sum_{t=1}^{\infty} \beta^t U(L_{s,t}, L_{p,t}, UT_t, C_t) \right]$$

The formulation of equation (13) represents a dynamic programming problem, which highlights the recursive structure of the decision problem. It is also said to be the *Bellman equation* named after Richard Bellman (1957) (see Gong and Semmler, 2004).

From equations (10) and (11) we can see that, the decision made at time  $t$  determines the state of economic environment at time  $t+1$ . Hence, in Gebre-Hiwot model, in every period  $t$  the government or policy maker faces the same decision problem: choosing the control variables

$C_t, UT_t$  that maximizes the current return plus the discounted return value of the optimum plan from period  $t+1$  onward.

Hence, we assume the objective of an infinitely living economic agent ( the government or policy maker here) is to maximize its entire life-time logarithmic utility function which is given by

$$MaxE_o \sum_{t=0}^{\infty} \beta (Log(L_{s,t}) + Log(L_{p,t})) \dots\dots\dots (14)$$

subject to the linear transitional dynamics equations of productive land and labour supply given by:

$$L_{s,t+1} = \delta L_{s,t} + \alpha C_t \dots\dots\dots (15)$$

$$L_{p,t+1} = \rho L_{p,t} + \phi UT_t \dots\dots\dots (16)$$

Prior to making a decision either to engage in unequal exchange and conflict, we have assumed rational economic agents believe that their action will not affect the economic environment (productive land and labour supply) negatively – fundamentally ignorant of or careless for effect of the dynamics. Hence, the sign of the coefficients of equations (15) and (16) takes the following form,

$$\alpha, \rho, \phi, \delta \geq 0$$

Rewriting equations (15) and (16) and substituting the result into equation (14) gives us the following equation.

$$MaxE_o \sum_{t=0}^{\infty} \beta (Log(\frac{L_{s,t+1} - \alpha C_t}{\delta}) + Log(\frac{L_{p,t+1} - \phi UT_t}{\rho})) \dots\dots\dots (17)$$

In this case, the Bellman equation is given by:

$$Max_{L_{s,t+1}, L_{p,t+1}} \{ (Log(\frac{L_{s,t+1} - \alpha C_t}{\delta}) + Log(\frac{L_{p,t+1} - \phi UT_t}{\rho})) + \beta V(L_{p,t+1}, L_{s,t+1}, C_{t+1}, UT_{t+1}) \} \dots\dots\dots (18)$$

Using the Euler approach, we derived the first order condition from the Bellman equation<sup>7</sup> by differentiating equation (18) with respect to  $C_t$ :

$$\frac{-\alpha}{L_{s,t+1} - \alpha C_t} + \beta E(\alpha \frac{\partial U(L_{s,t+1})}{\partial L_{s,t+1}}) = 0 \dots\dots\dots (19)$$

However, from the utility function of equation (14),

$$\frac{\partial U(L_{s,t}, L_{p,t})}{\partial L_{s,t}} = \frac{1}{L_{s,t}} \dots\dots\dots (19A)$$

Taking the lead of equation (19A), we obtain

$$\frac{\partial U(L_{s,t+1}, L_{p,t+1})}{\partial L_{s,t+1}} = \frac{1}{L_{s,t+1}} \dots\dots\dots (20)$$

Substituting equation (20) into equation (19) gives us

$$\frac{-\alpha}{L_{s,t+1} - \alpha C_t} = -\beta \alpha \frac{1}{L_{s,t+1}} \dots\dots\dots (21)$$

Rearranging equation (21) results in

$$L_{s,t+1} = (\frac{-\beta \alpha}{1 - \beta}) C_t \dots\dots\dots (22)$$

Taking the lag of equation (22), we found the amount of labour supply at time  $t$  is negatively related to the previous period political instability (conflict) and given by:

$$L_{s,t} = (\frac{-\beta \alpha}{1 - \beta}) C_{t-1} \dots\dots\dots(23)$$

Likewise, differentiating equation (18) with respect to  $UT_t$  gives

$$\frac{-\phi}{L_{p,t+1} - \phi C_t} + \beta E(\phi \frac{\partial U(L_{p,t+1})}{\partial L_{p,t+1}}) = 0 \dots\dots\dots (24)$$

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<sup>7</sup> In solving the dynamic optimization problem, it is common to employ the Euler and the Lagrangian equation first order conditions. The use of Euler equation is to write the optimized problem in such a way that the state variables at time  $t$  do not appear in the equation which is going to be optimized. Hence, the derivative is made with respect to time  $t+1$ 's state variable. The detailed derivation of this Euler equation is given in the appendix.

However, from the utility equation of (14),

$$\frac{\partial U(L_t, L_{p,t})}{\partial L_{p,t}} = \frac{1}{L_{p,t}} \dots\dots\dots (24A)$$

Taking the lead of equation (24A), we obtain

$$\frac{\partial U(L_{t+1}, L_{p,t+1})}{\partial L_{p,t+1}} = \frac{1}{L_{p,t+1}} \dots\dots\dots (25)$$

Substituting equation (24) into equation (23), we obtain

$$\frac{-\phi}{L_{p,t+1} - \phi UT_t} = -\beta\phi \frac{1}{L_{p,t+1}} \dots\dots\dots (26)$$

After rearranging equation (26), the total productive land at time  $t+1$  will be given by:

$$L_{p,t+1} = \left(\frac{-\phi\beta}{1-\beta}\right)UT_t \dots\dots\dots(27)$$

Lagging equation (27) gives us, the decision to engage in trade with unequal trading partner at time  $t-1$  affects the total productive land at time  $t$  negatively as given by:

$$L_{p,t} = \left(\frac{-\phi\beta}{1-\beta}\right)UT_{t-1} \dots\dots\dots (28)$$

**6. Conclusion**

In this paper an attempt is made to formalize the dynamic ideas of Gebre-Hiwot using a dynamic programming approach. Specifically, we have modeled the dynamics of conflict (political instability) and unequal exchange and their effect in the level of output (GDP). Based on Geber-Hiewot’s theory, conflict at any time  $t$  results in destruction of the labour force and hence its participation in productive activity both in current and subsequent periods. This is owing to its detrimental effect on total labour supply and hence agricultural

production of the country for the same and subsequent periods. Likewise, the decision to engage in unequal exchange (measured by the type of labour employed in producing the tradable commodities between two trading partners) at any time  $t$  results in 'terms of trade' deterioration, which exacerbates the problem of trade deficit of the developing country that is trading with the advanced country for the same period. This further will not allow economic agents to maintain the productivity of land which is now exhaustively exploited (degraded) and hence the implication for environmental degradation. The latter in turn lowers agricultural production (and hence GDP) for the subsequent period.

We believe this is the predicament that Ethiopia found itself in early 20<sup>th</sup> century as well as today in early 21<sup>st</sup> century. In fact this may depict the predicament of many developing countries even today. Gebre-Hiwot's imaginative mind has formulated the problems and suggested solution nearly a hundred years ago. We have attempted to give a mathematical formulation of that idea here. It is sad that there is no solution to this predicament even today. It is, thus, upon the present generation to bring an end to this predicament noted. The first step in that direction is analytical clarity using the modern language of economics as we have attempted to do in this paper. We hope econometricians will give it an empirical basis for this theoretical formulation and applied to Ethiopian data and beyond.

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## Appendix - A

Given the bellman equation

$$V_o \equiv \max_{\{u_t\}_{t=1}^{\infty}} \{ [U(x_t, u_t)] + \beta E(V_1(x_{t+1})) \} \dots\dots\dots (A1)$$

Where  $x_t$  is the state variable at time t and  $u_t$  is the control variable, subject to the transitional dynamic equation given by :

$$x_{t+1} = F(x_t, u_t) \dots\dots\dots (A2)$$

The first order condition of the right hand equation will takes the form

$$\frac{\partial U(x_t, u_t)}{\partial u_t} + \beta E \left[ \frac{\partial F(x_t, u_t)}{\partial u_t} \frac{\partial V(x_{t+1})}{\partial x_{t+1}} \right] = 0 \dots\dots\dots (A3)$$

However, in Euler equation first order condition the objective is to find  $\frac{\partial V}{\partial x}$ ,

Assume V is differentiable and from equation (A1) it satisfies

$$\frac{\partial V(x_t)}{\partial x_t} = \left[ \frac{\partial U(x_t, u_t)}{\partial x_t} + \beta E \left( \frac{\partial F(x_t, G(x_t))}{\partial x_t} \frac{\partial V(x_{t+1})}{\partial F} \right) \right] \dots\dots\dots (A4)$$

Where  $G(x)$  is the optimal level of control variable as a function of the state variable.

Moreover, at the optimum  $\frac{\partial F(x, G(x))}{\partial x} = 0$  hence, equation (A4) will become

$$\frac{\partial V(x_t)}{\partial x_t} = \frac{\partial U(x_t, u_t)}{\partial x_t} \dots\dots\dots (A5)$$

Taking the lead of equation (A5) and substituting it in equation (A3) give rise to the Euler first order condition:

$$\frac{\partial U(x_t, u_t)}{\partial u_t} + \beta E \left[ \frac{\partial F(x_t, u_t)}{\partial u_t} \frac{\partial U(x_{t+1}, u_{t+1})}{\partial x_{t+1}} \right] = 0 \dots\dots\dots (A6)$$

:

is



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