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## Technology, Learning, and Long Run Economic Growth in Leading and Lagging Regions

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# **Technology, Learning, and Long Run Economic Growth in Leading and Lagging Regions<sup>1</sup>**

by

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and

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# **Technology, Learning, and Long Run Economic Growth in Leading and Lagging Regions**

## **Abstract**

We use a dynamic model to study the effects of technology and learning on the long run economic growth rates of a leading and a lagging region. New technologies are developed in the leading region but technological improvements in the lagging region are the result of learning from the leading region's technologies. Our analysis sheds light on four salient questions. First, we determine the long run growth rate of output per human capital unit in the leading region. Second, we define a lagging to leading region technology ratio, study its stability properties, and then use this ratio to ascertain the long run growth rate of output per human capital unit in the lagging region. Third, for specific parameter values, we analyze the ratio of output per human capital unit in the lagging region to output per human capital unit in the leading region when both regions have converged to their balanced growth paths. Finally, we discuss the policy implications of our analysis and then offer suggestions for extending the research described here.

**Keywords:** Economic Growth, Lagging Region, Leading Region, Learning, Technology

**JEL Codes:** R11, R58, O33

## 1. Introduction

### *1.1. Overview of the issues and the literature*

Economists and regional scientists now understand that irrespective of whether one looks at a developed or a developing nation, there are inequalities of various sorts between the regions that comprise the nation under consideration. This comprehension has given rise to great interest in studying the characteristics of so called “leading” and “lagging” regions. In this dichotomy, leading regions are typically dynamic, frequently urban, they display relatively rapid rates of economic growth, and they are technologically more advanced. In contrast, lagging regions are generally not as dynamic, they are often rural or peripheral, they display slow economic growth rates, and they are technologically backward.

The intriguing subject of leading and lagging regions is part of a broader literature on spatial disparities.<sup>4</sup> In particular, the variability in regional socio-economic performance has given rise to much theoretical and empirical research.<sup>5</sup> This research has placed particular emphasis on the causal mechanisms responsible for persistent inequality between regions and on the policy levers for dealing with the attendant equity-efficiency tradeoffs. Clearly, productivity is a key factor in explaining and dealing with regional differences but this phenomenon calls for a deeper analysis of economic-geographic factors such as initial conditions, labor market inefficiencies, the availability of public services, the mobility of human capital, and technological progress. With regard to technology as a major engine of regional economic growth, learning mechanisms based on spatial networks and human capital linkages between competing areas have become a key “success factor”

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See Baumol (1986), Lucas (1988), Kochendorfer-Lucius and Pleskovic (2009), and Alexiades (2013) for more on this literature.

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See Armstrong and Taylor (2000), Fujita and Thisse (2002), and Nijkamp (2003) for additional details on this literature.

in equilibrating spatial growth patterns. In what follows, we pay particular attention to such interregional learning mechanisms in a spatial-economic system characterized by the existence of a leading and a lagging region. However, before we do this, let us concisely review the pertinent literature.

Ghosh and De (2000, p. 391) focus on the metric of income and point out that there are clear disparities in incomes between the leading and the lagging states in India. Their empirical analysis suggests that these income disparities can be addressed by the government “undertaking large infrastructure projects in lagging regions.” Kalirajan (2004) also focuses on India and notes that if one is to boost economic growth and promote growth spillovers from the leading to the lagging states, then it is essential to pay attention to the quality of human capital in the various states. Co and Wohar (2004, p. 101) look at technological convergence among various states/regions in the United States. On a hopeful note, their empirical analysis shows that there is “convergence (both beta and stochastic) in invention activities in three regions, in three leading states and in 16 lagging states.”

Nocco (2005) analyzes leading and lagging regions in terms of their initial technological gap and differences in what she calls trade costs. She studies conditions for the existence of interregional knowledge spillovers and notes that high trade costs result in the agglomeration of the modern sector in the leading region. Concentrating on Hungary since 1990, Brown *et al.* (2007, p. 522) point out that foreign capitalists tend to make human capital intensive investments in those parts of Hungary that already perform well. On a negative note, they claim that “no measure of institutional modernization is likely to make lagging regions attractive candidates for human-capital-intensive investments in the near future.” Desmet and Ortin (2007) study uneven development in a model with two regions and two sectors. They show that because there is uncertainty about which region

benefits from technological change, it may make sense for the lagging region to remain underdeveloped.

Rahman and Sakhawat (2009) use annual data from 1977-2000 to study per capita income convergence across six regions in Bangladesh. Their empirical study shows that if the lagging regions are to advance, then infrastructural, technological, and financial supports to the lagging regions will need to be intensified. The connection between leading and lagging regions in Brazil is the focus of Lall *et al.* (2009). These researchers point out that in addition to encouraging the formation of human capital, policies that increase welfare will need to improve access to and the quality of basic services in the lagging regions. Ghani *et al.* (2010) focus on convergence in South Asia and note that per capita incomes are not converging across the regions of South Asia. In addition, these researchers find substantial convergence in education indicators but not in measures of health. Finally, Krishna *et al.* (2010) point out that although trade liberalization reduces poverty throughout India, the strength of this effect is smaller in the lagging states. Therefore, these researchers contend that it is particularly important for the lagging states in India to be exposed to the salubrious effects of international markets.

## ***1.2. Contributions of our paper***

The various studies discussed in section 1.1 have advanced aspects of our understanding of the working of leading and lagging regions in different parts of the world. In particular, many of these studies have pointed to the salience of technology and human capital in enhancing the economic prospects of the lagging regions being studied. Even so, to the best of our knowledge, there are very few *theoretical* studies that explicitly link the trinity of human capital, technology, and learning when studying the economic growth prospects of leading and lagging regions.

Given this lacuna in the literature, the general objective of our paper is to use a dynamic model to analyze the effects of technology and learning on the long run economic growth rates of a stylized leading and a lagging region. Human capital is a key factor of production in both the leading and the lagging region. New technologies are developed in the leading region but technological improvements in the lagging region are the result of learning from the leading region's technologies. Our analysis sheds light on three salient questions. First, we determine the long run growth rate of output per human capital unit in the leading region. Second, we define a lagging to leading region technology ratio, study its stability properties, and then use this ratio to ascertain the long run growth rate of output per human capital unit in the lagging region. Third, for particular parameter values, we study the ratio of output per human capital unit in the lagging region to output per human capital unit in the leading region when both regions have converged to their balanced growth paths (BGPs).

The remainder of this paper is organized as follows. Section 2 describes our theoretical model of a leading and a lagging region that is inspired by Krugman (1979) and Grossman and Helpman (1991). Section 3 computes the long run growth rate of output per human capital unit in the leading region. Section 4 first specifies a lagging to leading region technology ratio, then examines this ratio's stability properties, and finally uses this ratio to determine the long run growth rate of output per human capital unit in the lagging region. Section 5 first provides values for certain parameters in our model and then uses these values to analyze the ratio of output per human capital unit in the lagging region to output per human capital unit in the leading region when both regions have converged to their BGPs. Finally, section 6 concludes and then discusses potential extensions of the research delineated in this paper.

## 2. The Theoretical Framework

Consider an *aggregate economy* consisting of a leading and a lagging region. We index these two regions with the subscript  $i$  where  $i=L,F$ . The subscript  $L$  denotes the leading region and the subscript  $F$  denotes the lagging or following region. The two factors of production (inputs) in each of the two regions at any time  $t$  are physical capital  $K_i(t)$  and human capital  $H_i(t)$ . These two inputs are employed either in the research and development (R&D) sector or in the final good sector.<sup>6</sup> To keep matters simple, we assume that there is no growth in the stock of human capital  $H_i(t)$ ,  $i=L,F$ . The technology available in the two regions at any time  $t$  is denoted by  $A_i(t)$ . The fraction of the human capital stock in the leading region that is employed in R&D is  $a_{H_L}$ . Hence,  $(1-a_{H_L})$  is the fraction employed in the final good sector.

The production functions denoting the outputs of the final good in each of the two regions are given by

$$Q_i(t) = K_i(t)^\beta \{A_i(t)(1-a_{H_i})H_i\}^{1-\beta}, \quad (1)$$

where  $\beta \in (0,1)$  is a parameter and  $i=L,F$ . The differential equation describing the accumulation of physical capital in the two regions under study is given by

$$\frac{dK_i(t)}{dt} = \dot{K}_i(t) = s_i Q_i(t), \quad (2)$$

where  $s_i \in (0,1)$  is the constant savings rate in region  $i$ ,  $i=L,F$ .

The leading region in our paper is leading in a precise technological sense. Specifically, new

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6

We suppose that the final goods in the leading and in the lagging regions are knowledge goods whose production requires skilled workers. This is why, in addition to physical capital, we are working with human capital as the second input and not directly with the labor available in these two regions. In this regard, note that whether it is more appropriate to work with human capital or with labor directly depends on the kind of final good production one is seeking to study.



technologies are developed *exclusively* in this region in accordance with the differential equation

$$\dot{A}_L(t) = B a_{H_L} H_L A_L(t), \quad (3)$$

where  $B > 0$  is a constant shift parameter. The lagging region is said to be lagging because in contrast with the leading region, this region does *not* develop any new technologies by itself. Instead, improvements in the technology possessed by the lagging region are the outcome of *learning* from the existing technology in the leading region.<sup>7</sup> We model this point by supposing that the stock of technology in the lagging region evolves in accordance with the differential equation

$$\dot{A}_F(t) = \theta a_{H_F} H_F \{A_L(t) - A_F(t)\}, \text{ if } A_L(t) > A_F(t); \dot{A}_F(t) = 0, \text{ if } A_L(t) \leq A_F(t), \quad (4)$$

where  $a_{H_F}$  is the fraction of the human capital stock in the lagging region that is responsible for learning the technology of the leading region. From this it follows that  $(1 - a_{H_F})$  is the fraction of the human capital stock in the lagging region that is employed in the final good sector. With this theoretical framework in place, our next task is to compute the long run growth rate of output per human capital unit in the leading region.

### 3. Long Run Output Growth in the Leading Region

The model of the economy of the leading region that we have just delineated in section 2 is a variant of the standard Solow growth model discussed thoroughly in Acemoglu (2009, pp. 26-71). In particular, from equation (3), it is clear that the growth rate of technology in the leading region is given by

$$\frac{\dot{A}_L(t)}{A_L(t)} \equiv B a_{H_L} H_L, \quad (5)$$

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7

One can also model learning by introducing a time lag in the use of technology in the leading and in the lagging regions.

which is constant. Now, adapting a standard result from the Solow growth model—see Acemoglu (2009, p. 65)—to our problem, it follows that the growth rate of output per human capital unit in the leading region is equal to the growth rate of technology and is hence given by equation (5). Our next task is twofold. We first specify a lagging to leading region technology ratio and then examine this ratio's stability properties. Next, we use this ratio to determine the long run growth rate of output per human capital unit in the lagging region.

#### 4. Technology Ratio Stability and Long Run Output Growth in the Lagging Region

Let  $R(t) \equiv A_F(t)/A_L(t)$  be the lagging to leading region technology *ratio* of interest. In order to examine the stability properties of this ratio, we will need to first find an expression for  $\dot{R}(t)$  as a function of  $R(t)$  and the parameters of the model. To this end, let us first differentiate the defining expression for  $R(t)$  with respect to time  $t$ . This gives us

$$\dot{R}(t) = \frac{A_L(t)\dot{A}_F(t) - A_F(t)\dot{A}_L(t)}{A_L(t)^2}. \quad (6)$$

We now substitute the expressions for  $\dot{A}_L(t)$  and  $\dot{A}_F(t)$  from equations (3) and (4) in equation (6) above and then simplify the resulting expression. We get

$$\dot{R}(t) = [\theta a_{H_F} H_F \{1 - \frac{A_F(t)}{A_L(t)}\}] - \{\frac{A_F(t)}{A_L(t)}\} \{B a_{H_L} H_L\}. \quad (7)$$

Next, we substitute the definition  $R(t) \equiv A_F(t)/A_L(t)$  in equation (7) and then simplify the resulting expression to get an equation for  $\dot{R}(t)$  in terms of  $R(t)$  and the parameters of the model. The equation of interest to us is

$$\dot{R}(t) = \theta a_{H_F} H_F - \{\theta a_{H_F} H_F + B a_{H_L} H_L\} R(t). \quad (8)$$

To analyze equation (8) in greater detail, we draw the phase diagram implied by this equation

**Figure 1 about here**

in figure 1. An inspection of figure 1 leads to three conclusions. First, the functional relationship between  $\dot{R}(t)$  and  $R(t)$  is linear. Second, the intercept term on the vertical or  $\dot{R}(t)$  axis is  $\theta a_{H_F} H_F > 0$ . Third, the slope of this functional relationship is negative and equal to  $-\{\theta a_{H_F} H_F + B a_{H_L} H_L\}$ . Before proceeding further, we point out that equation (8) and the phase diagram in figure 1 are not applicable when  $R(t) \geq 1$ . This is because equation (4) clearly tells us that  $\dot{A}_F(t) = 0$  whenever  $A_F(t) \geq A_L(t)$ .

Inspecting figure 1, we see that the graph of equation (8) intersects the horizontal or  $R(t)$  axis at the point  $R^* > 0$ . If  $R(t) < R^*$  then  $\dot{R}(t) > 0$ . In other words, if the ratio  $R(t)$  begins to the left of  $R^*$  then this ratio *rises* over time to the value of  $R^*$ . On the other hand, if  $R(t) > R^*$  then  $\dot{R}(t) < 0$ . Put differently, if  $R(t)$  begins to the right of  $R^*$  then this ratio falls over time to the  $R^*$  value. From this reasoning, it is clear that the lagging to leading region technology ratio in our model does converge to the *constant* stable value given by  $R^*$ . We can now compute the actual value of  $R^*$ . To do so, we set  $\dot{R}(t)$  from equation (8) equal to zero and then simplify the ensuing expression. This gives us

$$R^* = \frac{\theta a_{H_F} H_F}{\theta a_{H_F} H_F + B a_{H_L} H_L}. \quad (9)$$

Note that the right-hand-side (RHS) of equation (9) is composed of terms that are all constant and hence, consistent with our observation above, it follows that  $R^*$  itself is constant.

We now use equation (9) to ascertain the long run growth rate of output per human capital unit in the lagging region. The constancy of the lagging to leading region technology ratio tells us that in the long run, technology in the lagging region  $A_F(t)$  must be growing at the same rate as the technology in the leading region  $A_L(t)$ . This finding and the fact that our model is a variant of the Solow growth model together tell us that in the long run, the economy of the lagging region is, in fact, a Solow type economy in which the technology grows at the constant rate given by  $Ba_{H_L}H_L$ . Comparing this last result with equation (5), it follows that the long run growth rate of output per human capital unit in the lagging region is the *same* as the corresponding growth rate in the leading region.

The last result in the preceding paragraph has two interesting policy implications. First, this result tells us that even though the lagging region is technologically stagnant, from an economic growth perspective, as long as the authorities in the lagging region are patient, *no* growth stimulating policies are required because in the long run, both regions grow at the same rate. Second, the fraction of the human capital stock in the lagging region that is responsible for learning the technology of the leading region or  $a_{H_F}$  has *no* impact on the long run growth rate in the lagging region. Therefore, it is pointless for the authorities in the lagging region to attempt to spur economic growth by reallocating human capital from the final good sector to the sector engaged in improving the lagging region's technology by learning the technology of the more advanced leading region. This brings us to the last task in this paper. We now provide specific values for certain parameters in our model. Then, we use these values to examine the ratio of output per human capital unit in the lagging region to output per human capital unit in the leading region when both regions have converged to their BGPs.

## 5. The Two Region Output Per Human Capital Ratio and Balanced Growth

We begin by stating the specific values we shall be using for certain parameters in our model in this section. These values are

$$a_{H_L} = a_{H_F} \text{ and } s_L = s_F. \quad (10)$$

The first parametric specification in (10) tells us that the fraction of the human capital stock in the leading region that is employed in the R&D sector equals the corresponding fraction in the lagging region that is employed in learning the technology of the leading region. The second parametric specification in (10) says that the savings rate in the two regions under study are identical. These parametric specifications are made to keep the subsequent mathematical analysis tractable and to obtain concrete results.

Let  $A_L(t)H_L$  be the augmented human capital in the leading region. Then, dividing the production function for the final good in the leading region—see equation (1)—by this augmented human capital, we get

$$\frac{Q_L(t)}{A_L(t)H_L} = \left\{ \frac{K_L(t)}{A_L(t)H_L} \right\}^\beta \left\{ \frac{A_L(t)(1-a_{H_L})H_L}{A_L(t)H_L} \right\}^{1-\beta}. \quad (11)$$

To write equation (11) more compactly, let us make two definitions. First, let  $q_L(t) \equiv Q_L(t)/A_L(t)H_L$  be the output per augmented human capital unit in the leading region. Second, let  $k_L(t) \equiv K_L(t)/A_L(t)H_L$  denote the physical capital per augmented human capital unit in the leading region. Using these two definitions, we can rewrite equation (11) as

$$q_L(t) = k_L(t)^\beta (1-a_{H_L})^{1-\beta}. \quad (12)$$

We can now use the methodology described in Acemoglu (2009, pp. 26-71) to deduce that

on the BGP, we must have  $k_L^* = k_F^*$  or equality between the equilibrium values of the physical capital to augmented human capital ratios in the two regions. Taking the time derivative of the expression  $k_L(t) \equiv K_L(t)/A_L(t)H_L$  and then substituting equation (2) for  $i=L$  in the resulting expression, we get

$$\dot{k}_L(t) = \frac{s_L Q_L(t)}{A_L(t)H_L} - \left\{ \frac{\dot{A}_L(t)}{A_L(t)} \right\} \left\{ \frac{K_L(t)}{A_L(t)H_L} \right\} = s_L q_L(t) - Ba_{H_L} H_L k_L(t). \quad (13)$$

Substituting for  $q_L(t)$  from equation (12) in (13), gives us

$$\dot{k}_L(t) = s_L k_L(t)^\beta (1 - a_{H_L})^{1-\beta} - Ba_{H_L} H_L k_L(t). \quad (14)$$

Recall that the long run growth rate of output in the lagging region equals  $Ba_{H_L} H_L$ . Using this fact and a process similar to that employed in the derivation of equations (11) through (14) gives us the analog of equation (14) for the lagging region. The specific equation we seek is

$$\dot{k}_F(t) = s_F k_F(t)^\beta (1 - a_{H_F})^{1-\beta} - Ba_{H_L} H_L k_F(t). \quad (15)$$

Now, using the parametric specifications given in equation (10) in equations (14) and (15), we see that the differential equations describing the evolution of physical capital per augmented human capital unit or  $k$  in the two regions under study are *identical*. This tells us that the BGP values of  $k$  and  $q$  will also be the *same* for the leading and the lagging regions. In symbols, we have

$$k_L^* = k_F^* \text{ and } q_L^* = q_F^* \Rightarrow \frac{q_F^*}{q_L^*} = 1. \quad (16)$$

Let  $q_F \equiv Q_F(t)/A_F(t)H_F$ . Equation (16) and the definitions of  $q_F$  and  $q_L$  together imply that

$$\frac{A_F}{A_L} = \frac{Q_F/H_F}{Q_L/H_L}. \quad (17)$$

Equation (17) tells us that the lagging to leading region technology ratio (the LHS) is equal to the lagging to leading region ratio of output per human capital unit.

From our analysis in section 4, we know that in the long run, the lagging to leading region technology ratio converges to the constant and stable value  $R^*$  given by equation (9). Using equation (9) to substitute for the technology ratio  $A_F/A_L$  in equation (17), we get

$$\frac{\theta a_{H_F} H_F}{\theta a_{H_F} H_F + B a_{H_L} H_L} = \frac{Q_F/H_F}{Q_L/H_L}. \quad (18)$$

Inspecting equation (18), we see that because  $B a_{H_L} H_L$  is positive, the whole ratio is strictly less than one. This finding has three salient policy implications. First, we see that in contrast with our finding in section 4, output per human capital unit in the lagging region now will always be *less* than output per human capital unit in the leading region. Second and once again in contrast with the section 4 finding, on the BGP, the lagging to leading region output per human capital unit ratio *is* a function of  $a_{H_F}$  or the fraction of the human capital stock in the lagging region whose task is to improve the technology in this region by learning from the technology developed in the leading region. Finally, *ceteris paribus*, the larger is the fraction  $a_{H_F}$ , the more closely aligned will the trajectory of output per human capital unit in the lagging region be with the corresponding trajectory in the leading region. This completes our discussion of technology, learning, and long run economic growth in leading and lagging regions.

## 6. Conclusions

In this paper, we used a dynamic model to analyze the effects of technology and learning on the long run economic growth rates of a leading and a lagging region. New technologies were developed in the leading region but technological improvements in the lagging region were the result of learning from the leading region's technologies. Our analysis sheds light on four noteworthy questions. First, we determined the long run growth rate of output per human capital unit in the leading region. Second, we defined a lagging to leading region technology ratio, studied its stability properties, and then used this ratio to ascertain the long run growth rate of output per human capital unit in the lagging region. Third, for specific parameter values, we examined the ratio of output per human capital unit in the lagging region to output per human capital unit in the leading region when both regions had converged to their balanced growth paths. Finally, we discussed the policy implications of our research.

The analysis in this paper can be extended in a number of different directions. In what follows, we suggest two possible extensions. First, to increase the number of economic growth and development enhancing policy levers available to the authorities in the lagging region, it would be useful to study a model in which the stocks of human capital in the two regions grow over time. Second, it would also be helpful to examine the impact that trade between these two regions—possibly in goods embodying different skill levels—has on the growth and development of the leading and the lagging regions. Studies that incorporate these aspects of the problem into the analysis will increase our understanding of the nexuses between technology, learning, and the economic growth and development of leading and lagging regions.



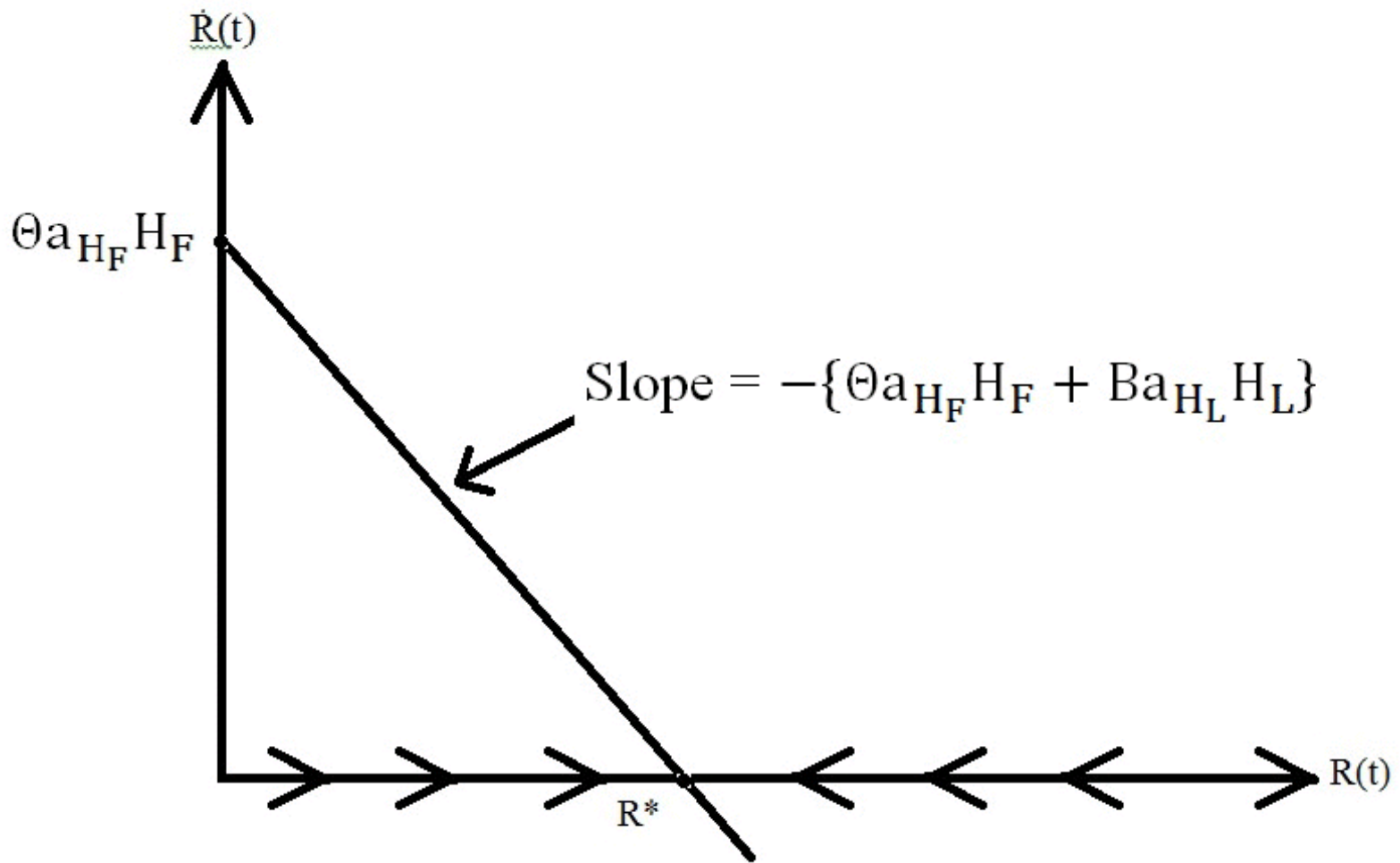


Figure 1

Phase Diagram

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