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sCIENTIFIC CYCLES: A DYNAMIC MODEL OF KUHNIAN THEORY

Dissertação apresentada à Faculdade de Economia, Administração, Contabilidade e Atuária da Universidade de São Paulo, como requisito parcial para a obtenção do título de Bacharel em Economia.

Orientador: Prof. Dr. Felipe Leon Peres Camargo Shalders

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1 Modelo de Crescimento; 2. Ciência; 3. Paradigma Científico

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Sumário

Resumo

Ciclos Científicos: um Modelo Dinâmico da Teoria de Kuhn

Objetivo: Entender como campos acadêmicos se desenvolvem através de mudanças de paradigmas, usando modelagem econômica **Método:** O modelo apresentado por (MATSUYAMA,1999) é reinterpretado como um modelo de desenvolvimento científico, que então é testado no Python, com seus parâmetros modificados **Resultados:** Conhecimento parece se beneficiar de ciclos alternados de produção científica dentro de um paradigma e fora.

Descritores: Modelo de Crescimento, Ciência, Paradigma Científico

ABSTRACT

CIENTIFIC CYCLES: A DYNAMIC MODEL OF KUHNIAN THEORY

Purpose: To understand how scientific fields develop through changes in paradigms, using economic modelling. **Method:** Reinterperting the model proposed in (MATSUYAMA, 1999), we derive a model of scientific development, that we then estimate on Python, seeing the effects of altering parameters **Results:** Knowledge seems to benefit from these alternating cycles of science production within a paradigm and science production without a paradigm.

Key words: Growth model, Science, Scientific Paradigm

1 INTRODUCTION

1 INTRODUCTION

1.1 INTRODUCTION

Throughout the 20th century philosophers studied how science was produced and developed. With a significant development by (POPPER, 1935), and his notion of falseability, with which he argued that science works by refuting theories by objective testing. Once a theory is refuted, it must be abandoned.

Then, in response to Popper, (KUHN, 1970) argued that no scientific field had such a linear development as was proposed, as scientists work within a *Paradigm,* in which there are uncontestable truths. As a *Paradigm* begins to fail to describe new aspects of reality, he remains in use until a new paradigm is developed, enveloping all that is already known, and the scientific community adheres to it.

In Kuhn’s proposition, there are two alternating moments in a scientific field: when the paradigm is working, and scientists produce within the paradigm, which is called a moment of Normal Science; and when the paradigm fails, and researchs must find solutions ouutside of the paradigm, in a moment that is called Revolutionary Science.

Following this proposition, (MERTON,1973) then opens the doors for the production of sociology of science, using methods of their field to understand the behavior of academics.

Though there are a few attempts to bring an economics perspective to analyse the scientific process, as seen in (BROCK, DURLAUF, 1998; PARTHA, DAVID 1994; STEPHAN, 2010), it is still a sparse field, and with little dialogue with the similar fields within philosophy and sociology.

More recently, (AKERLOF, MICHAILLAT, 2017) develops a model that tries to represent a part of Kuhn’s argument, as academics responsible for hiring new colleagues aim to hire young researchers that produce high quality research, while having a bias towards academics that adhere to the same paradigm as the agent. Although this brings great insight about the moment of adoption of new paradigms, it avoids the question of which context leads to the rise of new paradigms.

1.2 OBJECTIVES

This work aims to:

1. Develop a model of the alternance between moments of normal and revolutionary sciences;
2. Understand what promotes more frequent alterations to paradigms and research programs;
3. See if this changes to paradigm are beneficial to the development of the fields.

2 METHOD AND MODEL

1 METHOD AND MODEL

1.3 METHOD

Using the model from (MATSUYAMA, 1999) as basis, we reinterpret the variables as to describe the behavior of an academic field, renewing itself as their models and technologies get saturated.

Then, we input the model in Python 3, and analyse its dynamics, given diferent parameters.

1.4 THE MODEL

In this model, time, t, flows discretely, from 1 to infinity. The scientific enterprise will be represented by an economy with single final good, Knowledge, that can be consumed or used to encourage researchers into the next period. These researchers will be called K_{t-1}.

Before the group of researchers produce more knowledge, they must allocate themselves among a variety of research programs. These programs then become the final good through a symmetric CES. The production function is:

1. $Y_t = \hat{A}\left\{\int_0^{N_t} \left[x_t(z)\right]^{1-\frac{1}{\sigma}} dz\right\}$

where $x_t(z)$ indicates how much of the program z is being used by researchers at time t. The partial elasticity of direct substitution is $\sigma \in (1, \infty)$, and $\left[0, N_t\right]$ is the interval of possible research programs at the moment t.

At moment t, the academy works on all programs in $\left[0, N_{t-1}\right]$, with $N_0 > 0$. Alternatively, it may also be added programs $z \in \left[N_{t-1}, N_t\right]$, that exclusively produced by their creator in time t. The marginal cost of developing new programs is F researchers' time. The cost of production of both old and new research varieties is a units of researchers' time.

The marginal cost of production is constant and equal to a. Old research programs are produced competitively and, therefore, at their marginal cost:

$p_t(z) \equiv p^c = a$, for all $z \in [0, N_{t-1}]$. All new research programs, if they exist, are sold for $p_t(z) \equiv p^m = \frac{a\sigma}{\sigma-1}$, $z \in [N_{t-1}, N_t]$. Since the agregate production function uses the programs simmetrically, $x_t(z) \equiv x_t^c$, for $z \in [0, N_{t-1}]$, and $x_t(z) \equiv x_t^m$, for $z \in [N_{t-1}, N_t]$, satisfying the condition:

2. $\frac{x_t^c}{x_t^m} = \left[\frac{p_t^c}{p_t^m}\right]^{-\sigma} = \left[1 - \frac{1}{\sigma}\right]^{-\sigma}$

The monopoly of a period provided by the creation of a program encourages innovation, and there aren't any entry barriers to innovation. The profit of the development of a new program, considering the fixed cost, is $\pi_t = p^m x_t^m - \left(ax_t^m + F\right)$. Therefore, the profit is negative if, and only if, $ax_t^m < (\sigma - 1)F$. As there aren't any entry barriers

3. $ax_t^m \leq (\sigma - 1)F,\ N_t \geq N_{t-1},\ \left(ax_t^m - (\sigma - 1)F\right)\left(N_t - N_{t-1}\right) = 0$

This means that when scientists don't expect that the use of new research programs will reach the break-even point ($ax_t^m < (\sigma - 1)F$), there is no incentive to the production of new programmes ($N_t = N_{t-1}$). However, when there is innovation ($N_t > N_{t-1}$), the innovators operate at break-even, and consequently have no profit.

The researchers' time restriction at period t on the production of knowledge may be expressed as

$$K_{t-1} = N_{t-1}ax_t^c + \left(N_t - N_{t-1}\right)\left(ax_t^m + F\right)$$

Using the equations 2 and 3, the restriction above can be rewritten as

4. $ax_t^c = a\left[1 - \frac{1}{\sigma}\right]^{-\sigma} x_t^m = min\left\{\frac{K_{t-1}}{N_{t-1}}, \theta\sigma F\right\}$

and

5. $N_t = N_{t-1} + max\left\{0, \frac{K_{t-1}}{\sigma F} - \theta N_{t-1}\right\}$

Where $\theta \equiv \left[1 - \frac{1}{\sigma}\right]^{1-\sigma}$, depends positively on σ and its value goes from 1 to e, with σ going from 1 to ∞.

Using the equation 1, we have that the total scientific production equals

$$Y_t = \hat{A}\left[N_{t-1}\left(x_t^c\right)^{1-(1/\sigma)} + \left(N_t - N_{t-1}\right)\left(x_t^m\right)^{1-(1/\sigma)}\right].$$

Using the equations 3, 4, 5, we can rewrite the function as

6. $Y_t = \{A[\theta\sigma F N_{t-1}]^{1/\sigma}[K_{t-1}]^{1-(1/\sigma)},\ K_{t-1} < \theta\sigma F N_{t-1}\ AK_{t-1},\ K_{t-1} \geq \theta\sigma F N_{t-1}$

where

$A \equiv \frac{\hat{A}}{a}\left[\frac{a}{\theta\sigma F}\right]^{1/\sigma}.$

Equations 5 and 6 describe what happens on the the production side of academy at period t.

If $\frac{K_{t-1}}{N_{t-1}} \leq \theta\sigma F$, then there is no innovation, as K– the researchers' total time – is too small relative to the amount of research programmes, N. All programs produce science competitively, and the reduced form of the aggregate production function has all the usual proprieties of neoclassical growth theory, with decreasing returns on inputs. The academy is considered in *Solow State*, that we will consider equivalent to Kuhn's Normal Science Period. Note that a higher cost to inovation elongates this period. A higher substitution elasticity, σ, has the same effect, as it diminishes the gains of innovation.

If $\frac{K_{t-1}}{N_{t-1}} > \theta\sigma F$, the researchers have too much time for the number of programs, and new research programs arise. The reduced form of the aggregate model is linear in researchers' time in this interval, that may be called Revolutionary Science Program.

Now, to complete the model, it is necessary that we specify the the process by which the researchers of the new period are determined from the Knowledge produced in the previous period. We will simply assume that

7. $K_t = \mu Y_t$

That is, a constant fraction of what was produced serves as the basis of the next period's production. With that, the equations 5, 6 and 7 determine uniquely the equilibrium path for any initial conditions K_0 and N_0. This dynamic system is linearly homogeneous in K and N. Let us define

$$k_t \equiv \frac{K_t}{N_t\theta\sigma F}$$

such that the critical value of k, k^c, that separates both regimen of scientific production, be equal to 1. Our system may be then described as a one-dimension transformation, $\Phi: R_+ \rightarrow R_+$,

8. $k_t \; = \; \Phi\left(k_{t-1}\right) \equiv \{G(k_{t-1})^{1-(1/\sigma)}, \;\; k_{t-1} < 1 \; \frac{G(k_{t-1})}{1+\theta((k_{t-1})-1)}, \;\; k_{t-1} \geq 1$

where $G \equiv \mu A$. The equilibrium path for a initial condition k_0 is given by $\{\Phi_t\left(k_0\right)\}$, que $\Phi_t(k)$ is defined by induction, where $\Phi_1(k) \; = \; \Phi(k)$ and $\Phi_t(k) \; = \Phi(\Phi_{t-1}(k))$.

3 OUTCOME AND DYNAMICS

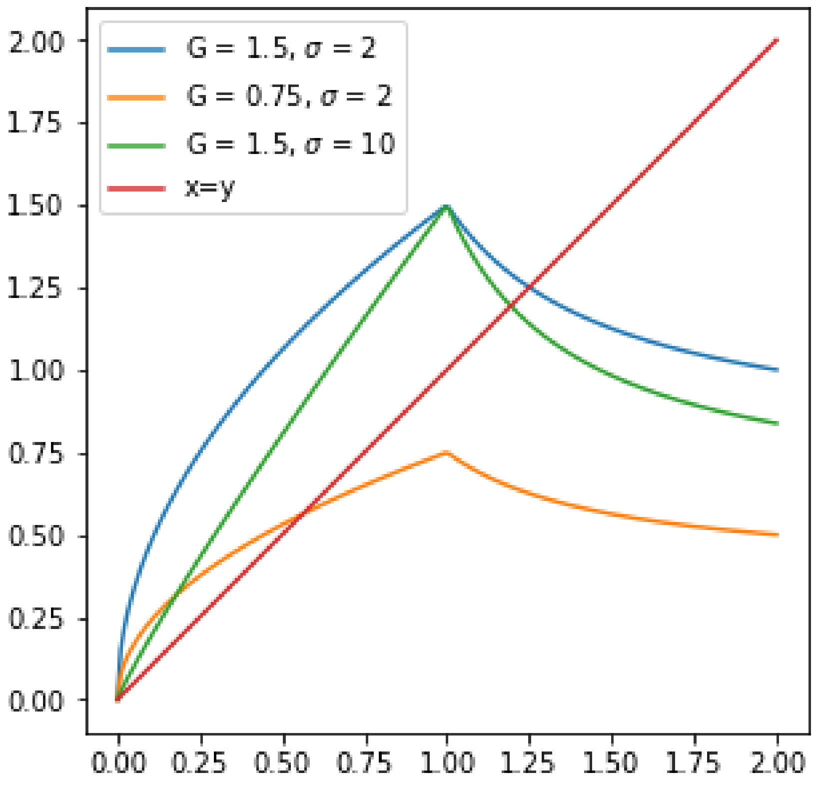
2 OUTCOME AND DYNAMICS

This dynamic system seen in equation 8 has a single steady state. If $G \leq 1$, the steady state is in the Normal Science regimen, given by $k_t = k^* \equiv G^\sigma \leq k^c = 1$. Without innovation, all research programs are provided competitively, and knowledge stagnates.

If $G > 1$, the steady state is in the revolucionary science regimen, given by $k_t = k^{**} \equiv 1 + (G - 1)/\theta > k^c = 1$. In ths steady state, new progras are developed constantly, and K and N grow at the same rhythm. This is the balanced growth path. From equations 6 and 7, $K_t = \mu Y_t = \mu AK_{t-1} = GK_{t-1}$, and as such G is equal to the gross growth rate. Note that $G = \mu A$ is the key parameter to determine the potential development of knowledge. If the parameter is greater than 1, research develops. If it is less than 1, knowledge stays stationary.

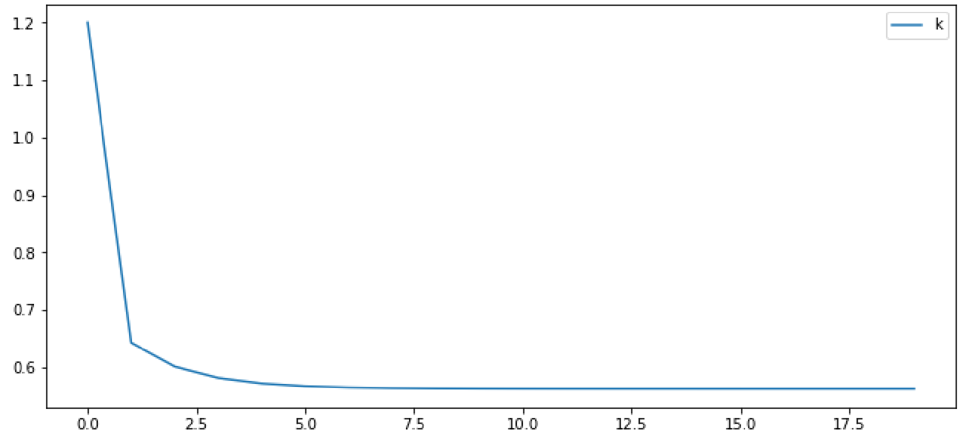
This is represented in image 1, as the steady states are represented as the crossing points between the function ϕ and the identity function. In orange, we can see G is 0.75, and the steady state is at the first part of the function ϕ. In the other 2 examples, G is greater than 1, generating steady states at the 'revolutionary' part of the function.

IMAGE 1 - STEADY STATE OF k



Both G and σ are essential to determine the long-term behavior of the academic field. When $G < 1$, the level of k stabilizes in a level lower than 1 as well, as can be seen in image 2, independent of the elasticity of substitution σ and k_0.

IMAGE 2- k WHEN $G = 0.75$ AND $\sigma = 2$



However, given $G > 1$, the behavior of k will chance dependent on σ. If $\phi^2(k^c) < k^c < \phi(k^c)$, the equilibrium path will alternate between moments of Normal science and moments of revolucionary Science. This interval is equivalent to $1 < G < \theta - 1$, as shown here:

$$\phi^2(k^c) < k^c < \phi(k^c) \leftrightarrow \phi(G) < 1 < G$$

$$\phi(G) = \frac{G^2}{1-\theta(G-1)} < 1$$

$$G^2 - 1 < \theta(G - 1)$$

$$G + 1 < \theta$$

As θ is uniquely determined by the elasticity of substitution σ, this alternating path will appear when σ is large enough, as seen in image 3. Otherwise, growth will stabilize in the balanced growth path, in which both K and N are constantly growing, at the same pace. That can be seen in image 4.

As shown, growth of K along the balanced growth path equals G, and from equation 6, we know that growth of Y must follow the same rhythm. From equation 6, we also know that Y does not grow in the normal science stationary path, as both K and N also do not grow.

As can be seen in image 5, growth in the alternating path is greater than in balanced growth path and, as such, greater than G.

IMAGE 3 - k WHEN $G = 1.5$ AND $\sigma = 10$.

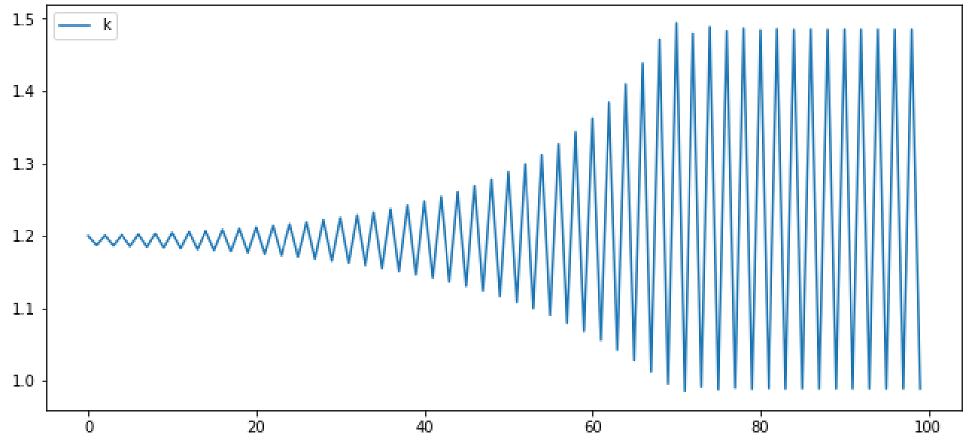


IMAGE 4 - k WHEN $G = 1.5$ AND $\sigma = 2$.

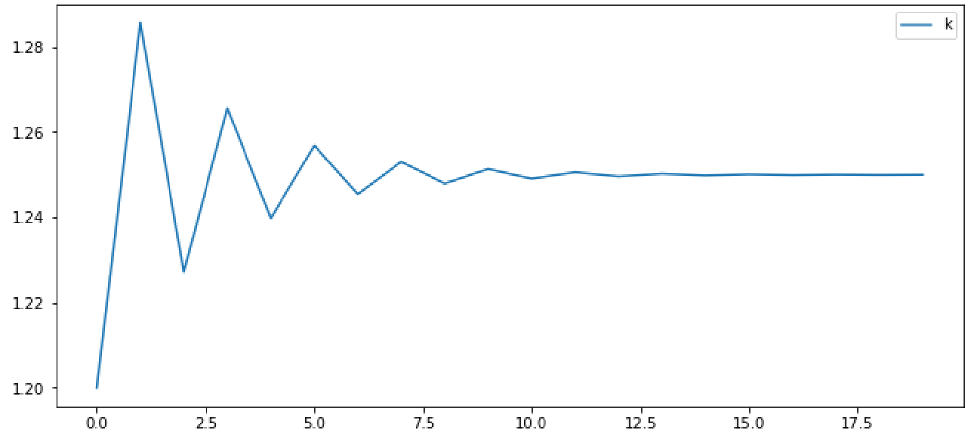
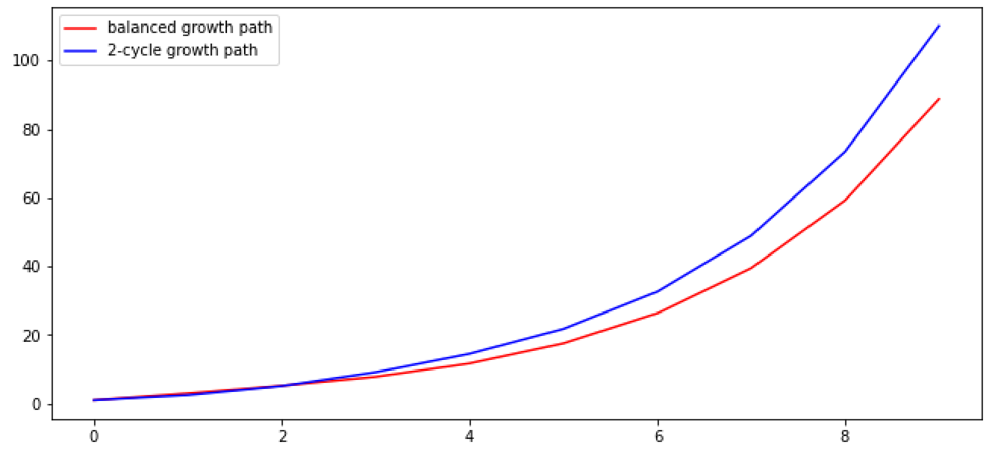


IMAGE 5 – COMPARING GROWTH PATH.



4 DISCUSSION

3 DISCUSSION

Most other research by economists on scientific, such as (AKERLOF, MICHAILLAT, 2017; BROCK, DURLAUF, 1998), developed models that give an understanding of paradigm choice and adherence at the “micro” level, looking at how individuals optimize this choice.

Bringing an alternative view, we look at the aggregate effects of this choices, and try to analyse the quality of the science produced given the general context of the field. Looking at problem from this manner, we can ask questions about the quality and quantity of research produced, and which caracteristics of the field might incentivize such development.

A potential future study might be able to bring both perspectives together so that we may have a clearer view of how all parts interact.

5 CONCLUSION

4 CONCLUSION

As was shown in the model, the most efficient way for Knowledge to develop is in growth path that alternates between moments of Normal Science, in which everyone works within a paradigm, and moments of Revolutionary Science, in which part of the scientific community focus on developing new methods.

This alternance may incentivized by an increase in the elasticity of substitution between different agendas, which may be interpreted as an easier communication between these different research agendas, and therefore more mixture between different fields. Another way to incentivize development of new agendas may be to reduce the fixed costs associated with it, which is something that universities already do, with tenure.

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