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Endogenous growth and entropy☆

Tiago Neves Sequeira[a,b,d], Pedro Mazeda Gil[c,*], Oscar Afonso[c,b]

[a] University of Beira Interior, Portugal
[b] CEFAGE-UBI, Portugal
[c] University of Porto and CEF.UP, Portugal
[d] Universidade da Beira Interior. Avenida Marques d'Avila e Bolama, Covilhã 6200-001, Portugal

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ABSTRACT

This paper offers novel insights regarding the role of complexity in both the transitional and the long-run dynamics of the economy. We devise an endogenous growth model that encompasses long-run economic change building on the concept of entropy as a time-varying state-dependent complexity effect. We show that the empirical evidence supports entropy as an 'operator' of the complexity effect. It also suggests that part of the modern innovations have a stabilizing role in the complexity of the economies, as the 'operator' levels off despite the continuous increase in the measure of technological varieties. The model features endogenous growth, with null or small scale effects, or stagnation, in the long run. The model can replicate well the take-off after the industrial revolution and the productivity slowdown in the second half of the XXth century. Long-run scenarios based on in-sample calibration are discussed, and may help explain (part of) the growth crises affecting the current generation.

1. Introduction

Our paper studies long-run economic change by building on the interplay between endogenous growth and scale effects through the evolution of an 'operator' based on the concept of entropy. We take advantage of the proximity between the entropy concept, as a measure of disorder, redundancy or diversity (as developed in Thermodynamics, Information Theory, and Biology, respectively) and the complexity associated with the quantity of knowledge or technological varieties in

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* Corresponding author.
E-mail addresses: sequeira@ubi.pt (T.N. Sequeira), pgil@fep.up.pt (P.M. Gil).

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Economics to build our 'operator' as a complexity index, which is time-varying solely by means of its state (knowledge) dependence. Thus, this index works as a 'summary statistics' of the relevant macroeconomic behavior pertaining to this issue with a minimum loss of information. When taken to the data, our model based on an 'entropy' complexity effect on the production of knowledge suggests that at least part of the innovations of the current generation have a stabilizing effect on the complexity of the economy, as the complexity index levels off despite the continuous increase in the stock of available knowledge. In fact, this can be interpreted from the macro-behavioral point of view as reflecting a relatively high level of complementarity of ideas in the modern knowledge system. In particular, this paper focuses on the structural characteristics of knowledge production that lead to various types of macro behavior and to changing (and possibly different) patterns of development.

The entropy 'operator' that governs the economy complexity allows for both transitional dynamics in the stock of knowledge and the dilution of strong scale effects in the long run. In fact, in spite of the modern evidence against (strong) scale effects on economic growth,[1] historical evidence indicates that the level of the population and connections between civilizations determined economic growth rates (e.g., Kremer, 1993; Sokoloff, 1988). Until now, the apparent contradiction between the today's evidence and the historical evidence on the existence of scale effects has not been completely incorporated into the economic growth literature, although some attempts have been made. Dinopoulos and Thompson (1998) briefly mentioned this dichotomy and showed that it can be approached through the analysis of transitional dynamics; see also, e.g., Jones (2002), Peretto and Smulders (2002), Davis (2008) and Strulik et al. (2013). In turn, Alesina et al. (2005) showed that not only is there historical evidence of significant scale effects, but also there may be some scale effects nowadays if both size and openness are taken as joint determinants of economic growth. Therefore, we conciliate the existence of scale effects long ago in history with evidence of no or reduced scale effects in today's economies, by considering a time-variable state-dependent 'operator' that is also flexible enough to account for some, negative or positive, scale effects even in the long run. Transitional dynamics occur independently of the consideration of decreasing marginal returns to physical capital and of time-varying growth rates of physical inputs to knowledge production and may be non-monotonic (inverted-U shaped), also by the sole action of the 'operator', which contrasts with the previous literature and addresses the non-linear behavior also observed in the data on growth rates.

Moreover, the dynamical system in our model inherits the piecewise-continuous structure that arises in the innovation-driven endogenous growth models, and that may originate an interesting path-dependency. This structure reflects that, if the expected profit of R&D is not sufficiently large in order to exceed the respective cost, then there is a corner solution at which no R&D occurs. Our paper takes this feature explicitly into account in line with, e.g., Strulik et al. (2013) and Peretto (2015), to study the switch from stagnation to innovation-driven growth and, also a possibility in our model, from growth to stagnation again – as a result of the interaction, over time, between (positive or negative) scale effects commanded by the complexity index and knowledge accumulation and population growth.

We calibrate the complexity index with empirical data and show that the transitional dynamics in the model can match well the historical evolution of TFP and per capita GDP in the developed world after the Industrial Revolution, as well as predict the productivity slowdown after the 1960s. Moreover, since the calibrated complexity index eventually stabilizes despite an ever-increasing measure of technological varieties, it is apparent from the model that new ideas (and new varieties of technological goods) have a heterogeneous impact on complexity, with some increasing it and others decreasing it. The obtained calibration of the complexity index suggests, in particular, that there is a relatively high complementarity (and, thus, low substitutability) of ideas or, alternatively, a relatively high 'relative risk aversion' to adopt new ideas in modern economies.

Given the flexibility introduced by the complexity index as regards the remaining scale effects in the long run (null or small positive or negative), we are able to predict contrasting scenarios for the long-run dynamics: there will be positive economic growth in the long run, although possibly lower than over the XXth century, despite (eventual) population stagnation; or economic stagnation will occur due to population growth (although the latter will eventually stagnate in the long run).

Our paper is particularly close to Peretto and Smulders (2002) and Dalgaard and Kreiner (2003). The latter take a general point on the asymptotic properties of a knowledge production function of the type $A_{t+1} = f(A_t, L_t^A)$, where A is the stock of ideas or knowledge, L^A summarizes the physical factors affecting the production of knowledge and t is the time index. In order to obtain endogenous growth, the derivative of $f(A_t, L_t^A)$ with respect to A_t must be constant and larger than unity in the long run (i.e., asymptotically). That is, endogenous growth requires that an increase in the stock of knowledge, even when this stock is already infinitely large, still leads to some new ideas. Peretto and Smulders (2002) study an endogenous growth model of vertical and horizontal R&D that exhibits scale effects (which may be positive or negative) over time but that always vanish asymptotically. They model the incremental process of increasing complexity in an expanding economy as follows: vertical R&D expands the public knowledge stock and gives rise to spillovers, while horizontal R&D leads to higher specialization in R&D activities and an increased technological distance between firms, thereby diluting spillovers and causing the scale effects to vanish asymptotically. In turn, our paper addresses the interplay between endogenous growth and scale effects by considering an 'operator' that introduces concavity with respect to knowledge in the knowledge production

[1] Growth rates have not always accelerated globally as population increased and bigger countries do not grow systematically at higher rates than smaller ones.