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Formal definitions of information and knowledge and their role in growth through structural change

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ABSTRACT

The article provides a way to quantify the role of information and knowledge in growth through structural adjustments. The more is known about environmental patterns, the more growth can be obtained by redistributing resources accordingly among the evolving sectors (e.g. bet-hedging). Formal equations show that the amount of information about the environmental pattern is directly linked to the growth potential. This can be quantified by treating both information and knowledge formally through metrics like Shannon's mutual information and algorithmic Kolmogorov complexity from information theory and computer science. These mathematical metrics emerge naturally from our evolutionary equations. As such, information becomes a quantifiable ingredient of growth. The policy mechanism to convert information and knowledge into growth is structural adjustment. The presented approach is applied to the empirical case of U.S. export to showcase how information converts into growth potential.

The Nobel-laureate and co-founder of the Santa Fe Institute, Murray Gell-Mann, came to the conclusion that although complex systems "differ widely in their … attributes, they resemble one another in the way they handle information. That common feature is perhaps the best starting point for exploring how they operate" (1995; p. 21). The article uses formal definitions of information and knowledge from information theory and computer science, links them to related definitions from evolutionary economics, and showcases the how information can inform structural change in the economy. Information theoretic metrics of information naturally emerge from evolutionary decompositions of growth and can directly be linked to the growth potential due to the redistribution of resources (i.e. structural change of the economic population).

An intuitive micro-economic example will set the stage and introduce the presented argument. Imagine a bakery that produces salty and sweet goods. If nothing else is known about the future environment, economic evolution would suggest to let market selection winnow out the more profitable among these two business options (Nelson and Winter, 1985). However, if we have information about

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future dynamics, it might be profitable to intervene into market selection. Recent big data analysis of statistical patterns has revealed that the demand for sweet goods grows with rain and the demand for salty goods with sunshine. This information about the environment allows to adjust the structure of its product offerings to the identified environmental pattern. The more it knows about the relation, the more growth potential. Being aware of this relationship and the environmental pattern with regard to rain and sunshine, productivity increments of up to 20% have been reported for individual bakeries (Christensen, 2012). The potential to grow depends on what is known about the uncertain future environment.

The article shows how information and the resulting growth potential relate through a logic of bet-hedging. This is includes two steps. “On the one hand there is a need to observe and to know, on the other hand there is a need to modify the external environment” (Saviotti, 2004; p. 101). Or to use the well-known concepts from Lundvall and Johnson (1994): for one we need to ‘know what’ (e.g. the relation between baked goods and the weather), and additionally we need to ‘know how’ (e.g. how to redistribute proportions to optimize growth). We will use a simple evolutionary decomposition of growth to formalize the optimal relationship between growth and the distribution of the evolving population (be it proportions of baked goods or shares of economic sectors). We will forgo the details of how this redistribution can be implemented in practice (as there is a large variety of options available), but focus on the fact that there is a formal and quantifiable relation between the amount of information and the potential to grow. The more is known about the future, the more efficient can be the restructuring, the higher the obtainable growth rate. Better information and the respective redistribution of resources hinge upon each other. This converts formal definitions of information and knowledge into a quantifiable input for economic growth. Longstanding information theoretic metrics of information emerge as an integral part of our evolutionary equations, including Shannon’s (1948) entropy and mutual information, Kullback-Leibler’s relative entropy (1951), Massey’s directed (causal) information (1990), and Kolmogorov’s algorithmic information/knowledge (i.e. Kolmogorov (1968) complexity). These metrics are traditionally used in engineering, physics and computer science, but turn out to be very useful when conceptualizing economic dynamics. The policy tool to convert information and knowledge into growth is structural change through the redistribution of resources among the constituent sectors of an evolving economic population.

A formalization of the relation between information and knowledge and growth becomes increasingly important in a big data world in which a myriad of previously unknown environmental patterns are identified thanks to the unprecedented amount of available information about all kinds of dynamics and structures (e.g. Mayer-Schönberger and Cukier, 2013; Hilbert, 2016). It is claimed that the “data-driven economy” (European Commission, 2014) thrives on plain “data as a new source of growth” (OECD, 2013). The article shows how formal notions of information and knowledge extracted from data relate to growth through structural change, which formalizes the idea of “harnessing big data to unleash the next wave of growth” (Manyika et al., 2011).

The article consists of four main parts. It first introduces the formal metrics used to quantify information and knowledge, such as “Kolmogorov complexity” and “Shannon information”. References are made to related conceptualizations from the literature of evolutionary economics and business knowledge management to put these mathematical notions into the existing social context. The next section uses a complete decomposition of growth and introduces the logic of bet-hedging. Bet-hedging can be shown to optimize growth given existing information/knowledge about environmental patterns. This follows the basic result of Kelly (1956) and more recent contribution in the field of portfolio theory and biological bet-hedging. The third section provides empirical evidence of the derived results. It quantifies the role of information for potential structural adjustments in the U.S. export economy. The final sections discuss the underlying assumptions of the presented logic and possible extensions.

1. How to formalize “knowledge” and “information”?

We start by defining our notions of information and knowledge. There is a desperate need for “sharpening the distinctions between information and knowledge… [last but not least, due to] the continued acceleration of innovations in information and communication technologies” (Cohendet and Steinmueller, 2000; p. 195). We will turn the tables of this momentum and use the proper definitions of information and knowledge employed by information and communication technologies to distinguish between them. In agreement with the well-known data-information-knowledge framework from the business knowledge management literature (Ackoff, 1989; Zeleny, 1986), also in information theory “information is defined in terms of data, knowledge in terms of information” (Rowley, 2007; p. 163). Also engineers and computer scientists see “information and knowledge are two very different, although related concepts” (Saviotti, 2004; p. 105). It turns out that formal definitions of knowledge (in form of “Kolmogorov complexity”) and information (in the form of “Shannon entropy”) are two sides of the same coin. Just like two sides of a coin, they are not identical, but they are two complementary ways of showing the same average quantity.

1.1. Data, information, and knowledge in information theory

In information theory, *data* is usually defined as symbols without any meaning or value. Data is defined as *any distinction, any perceivable difference*. This variation can be visual, auditory, tactile, olfactory, gustatory, imagery, or dynamic in time, etc. Digital data are represented as different kinds of differences, the most fundamental of them being binary, such as current or no current (in an electronic circuit), light or no light (in a fiber-optic cable), certain wave or not (in cellular frequency spectrum), etc.