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Empirical validation of Metcalfe's law: How Internet usage patterns have changed over time

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ABSTRACT

Few doubt that Digital Information Networks (DINs) such as the Internet constitute the basis of a new technology-driven economic era. A large body of literature tries to understand and quantify the value of DINs to help policy makers justify investments in new or improved infrastructures. The prevailing methodological approach is to depict DINs as an observable production input changing the uncertainty regarding the performance of an economic system. In such context, the value of DINs is typically measured with regression techniques between the penetration rate of DINs and economic growth. This approach provides too little insight on the actual causality between DINs and economic value. We recently developed a framework that identified 13 different ways (''capabilities'') how users convert information into economic value. In this article, we show how a simple quadratic relation (Metcalfe's law) can be used to quantify how adequate these capabilities are in converting the ability to access information into economic value. To our knowledge, this is the first time that Metcalfe's law is empirically validated as such.

1. Introduction

Since the 1980s, the telecommunication sector has been expanding rapidly (Shiu and Lam, 2008). This is mainly caused by the conversion of analoge communication networks designed for telephony or TV services into multi-functional Digital Information Networks (DINs). The exponential growth of services offered over DINs can be explained by many factors, including technological advancements, market liberalization and privatizations. The worldwide extraordinary level of interest in deploying information networks is due to the strong perception that information networks bring economic, social and environmental benefits (Firth and Mellor, 2005). Some authors speculated that DINs may have a similar impact on society as transportation networks had during the 20th century (OECD, 2001). In long wave theory, this information driven economic era is known as the 5th Kondratieff economic cycle (Perez, 2003). A Kondratieff cycle manifests itself by a sinusoidal-like long-term cycle from approximately 40 to 60 years in length with a semi-period of high productivity growth followed by a semi-period of relatively slow growth (Freeman and Louçã, 2001). The benefits of DINs can be observed directly. For example, construction of network infrastructures leads to direct increase in job employment. In addition, the benefits might also be more intangible, such as better quality of health care services,

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improved education and organizational efficiency. The Organization for Economic Co-operation and Development (OECD) considered broadband DINs as key to enhancing competitiveness and sustaining economic growth (OECD, 2001). Many governments are increasingly committed to extending DINs to their citizens (Katz et al., 2009), particularly in the developing nations (Kagami et al., 2004). Consequently, the levels of interdependency between users and DINs' providers increased dramatically (Dijk and Mulder, 2005) and the DIN infrastructure became an essential facility for all economic sectors.

In order to justify policy support for further investments in DINs (e.g. in Fiber To The Home (FTTH)), it is necessary to learn from expenditures that have already been made and demonstrate their value. We recently developed a Holonic Framework (HF) which identified and defined so-called "capabilities" of users in DINs (Madureira et al., 2011). Capabilities are mechanisms that users apply to convert information into economic value. In this article, we show how a simple quadratic relation (Metcalfe's law) can be used to quantify how adequate these capabilities are in converting the ability to access information into economic value. To our knowledge, this is the first time that Metcalfe's law is empirically validated as such.

The next section describes the state of the art on studies aiming at understanding the value of DINs, including a brief overview of our HF. Section 3 provides the equations with which the behavior of the capabilities of the HF can be quantified. The characteristics of our data source, our conceptual operationalizations and our validation methodology are described in Section 4. The results of our analysis are presented in Section 5, whereas Section 6 discusses them, identifies potential implications, and describes the limitations of our work. The last section is reserved for our conclusions.

2. State of the art

We reviewed 24 studies on the value of DINs spanning a period from 1980 to 2010. These studies can be grouped into three classes: (1) macro-economic studies using general equilibrium theories and/or input–output tables (Katz et al., 2009; Greenstein and McDevitt, 2009; Correa, 2006; ACIL Tasman, 2004; CEBR, 2003; Röller and Waverman, 2001; Hardy, 1980); (2) econometric studies not addressing the issue of causality (Thompson and Garbacz, 2008; Thompson and Garbacz, 2007; Shideler et al., 2007; Duggal et al., 2007; Crandall et al., 2007; Lehr et al., 2006; Datta and Agarwal, 2004; Sridhar and Sridhar, 2004; Madden and Savage, 2000; Madden and Savage, 1998; Greenstein and Spiller, 1995; Leff, 1984); and (3) econometric studies addressing causality deterministically (Majumdar et al., 2010; Koutroumpis, 2009; Shiu and Lam, 2008; Ford and Koutsky, 2005; Cronin et al., 1991). The first class of studies provide a tool to policy analysts to study the effect of DINs across the interdependences and feedbacks of an economy (Borges, 1986). Empirical validation is not addressed due to the nature of the underlying assumptions, e.g. perfectly rational behavior and equilibrium solutions (Farmer and Foley, 2009). Hence, claims such as "the economic impact of broadband development over a ten year period in Germany amounts to 968,000 additional jobs" (Katz et al., 2009) tend to have a speculative character.

Madden and Savage (1998) found that the causality between DINs and economic growth works in both directions. Similar observations were made by Shiu and Lam (2008) who observed a "bidirectional relationship between telecommunications development and economic growth for European countries and those belonging to the high-income group". Thus, the direction of causality is a methodological challenge inherent in disentangling the value of DINs. The results of the class 2 studies, not addressing causality, should therefore be interpreted cautiously. Recently, some econometric studies (class 3) have addressed the issue of causality deterministically. In such context, the value of DINs is typically measured with regression techniques between the penetration rate of DINs and economic growth. However, this approach provides few insights on the actual causal mechanisms that explain how DINs generate value.

In Madureira et al. (2011), we described a framework, labeled Holonic Framework (HF), that provides an overarching account for the intermediate processes between DINs and economic value. The HF provides deeper insights on the causality between DINs and economic value than the economic studies mentioned above. From extensive literature analysis, the HF identifies 13 different ways (so-called "capabilities") how users apply convert information into economic value. Here, they are simply postulated and defined in Table 1, in no particular order. To name a particular capability we mixed action/verb/process specifics, being aware that the result is not always in line with English grammar. For more information on the HF we refer to Madureira et al. (2011) and Madureira (2011).

3. Model for value generation by users in DINs

We can derive a number (value) for how effective a capability is in creating economic value from how it is used to generate income. For example, if a worker uses DINs for online education, then he uses adoptability to obtain a certain part of his income. The value (y_c) generated by a capability c is dependent on the size x of the DIN. With a larger network more value is extracted by a capability. k_c is the coupling strength between the size of the network and the value generated by capability c, and is a measure for c's effectiveness in creating value by accessing information. We assume that the size of the DIN and the coupling strength of each capability are independent.

Metcalfe's law states that the value of a network is proportional to the square of its size, relying on the observation that for a network with n members, each can make $n-1$ connections with the other members (Metcalfe, 1995). If all those connections are equally valuable, the total value of the network is proportional to $n(n-1)$, thus roughly to n^2. For example, if a network has 5 members, there are 20 different possible connections that members can make to each other. If the network doubles its size to 10 members, then the number of connections does not simply double, but roughly quadruples to 90.