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On the emergence of scale-free production networks

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ABSTRACT

We propose a simple dynamical model for the formation of production networks among monopolistically competitive firms. The model subsumes the standard general equilibrium approach à la Arrow–Debreu but displays a wide set of potential dynamic behaviors. It robustly reproduces key stylized facts of firms' demographics. Our main result is that competition between intermediate good producers generically leads to the emergence of scale-free production networks.

1. Introduction

The scale-free nature of a wide range of socio-economic networks has been extensively documented in the recent literature (see e.g. Barabási, 2009; Gabaix, 2009; Schweitzer et al., 2009). However, very few contributions have investigated the micro-economic origins of these structures. In this paper, we approach the issue in the context of production networks.

We propose a simple model of out-of-equilibrium dynamics that accounts for the endogenous formation of supply relationships. The main insight gained from the model is that the emergence of scale invariance is a natural implication of competition under the two following assumptions: the number of incoming business opportunities for a firm is independent of its size and the rate at which existing consumers may quit grows linearly with the size of the firm. Scale-free structures then balance the speed at which firms grow and shrink. In other words, competition inherently induces the formation of scale-free structures. This result suggests that institutional aspects of economic activity could explain empirical findings about the distribution of firms' size (see Axtell, 2001) as well as the emergence of aggregate volatility, which is related to the presence of fat tails in production networks according to Acemoglu et al. (2012).

The backbone of our approach is a model of monopolistic competition on the markets for intermediate goods, akin to the one introduced by Ethier (1982) (on the basis of Dixit, 1977) and popularized by the endogenous growth literature (see e.g.

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Romer, 1990). In this framework, we represent supply relationships as the weighted edges of a network and consider out-of-equilibrium dynamics in which (i) demands are made in nominal terms and sellers adjust their prices to balance real supply and nominal demand and (ii) firms progressively adjust their production technologies (i.e. the network weights) to prevailing market prices. When the set of relationships is fixed (i.e. only the weights of the network can evolve), the identification with the underlying general equilibrium model is perfect in the sense that (i) the adjacency matrix of the network is in a one to one correspondence with the underlying general-equilibrium economy and (ii) the model converges to the underlying general equilibrium. However, the context of interest for us is the one where the technological structure is not fixed a priori and where, the different production goods being assumed substitutable, firms can, in the long-run, adjust their production technologies/supply relationships as a function of market prices. Then, we show that the model does not in general admit a steady-state, but settles in a dynamic regime where the distribution of firms' size and the structure of the production network are scale-free.

Beyond the emergence of scale-free networks, the model consistently reproduces a rich set of stylized facts of firms' demographics: firms' sizes are Zipf distributed, firms' growth rates follow a Laplace distribution, the variance of growth rates decreases with size, and there is a negative correlation between firms' exit rates and age. This set of stylized facts can be reproduced by a relatively parsimonious model (a simple out-of-equilibrium extension of the Arrow–Debreu framework) and for a relatively large range of parameters.

Although there exist micro-foundations for some of these stylized facts in the general equilibrium literature, they have rarely been jointly analyzed. More importantly, the general equilibrium literature on firms' demographics makes very strong assumptions about the information available to firms, their farsightedness and their rationality. Its results also rely on very specific assumptions about the distribution of exogenous shocks faced by the firms. In this framework, it is rather difficult to understand what are the actual driving forces of firms' demographics. In contrast, we offer a parsimonious model and a simple explanation of the emergence of fat tails as a consequence of the asymmetric effects of competition on firms of different size.

The remainder of the paper is organized as follows. In Section 2, we discuss the relation of our approach to the literature. In Section 3, we give a detailed description of the model and provide a theoretical analysis of its asymptotic properties. In Section 4, we analyze, via numerical simulations, the stability properties of the model and the detailed properties of firms' demographics emerging from its dynamics. Section 5 concludes.

2. Related literature

The network perspective on production structures has been introduced in a series of contributions that investigated the propagation of shocks in economic systems (see in particular Bak et al., 1993; Scheinkman and Woodford, 1994; Weisbuch and Battiston, 2007; Battiston et al., 2007; Acemoglu et al., 2012). Our approach builds on this analogy between input–output structures and directed networks, but focuses on the network formation process and the emergence of scale-invariance. In this respect, it is related to the wide literature on the determinants of the distribution of firms' size and more generally firm demographics. A first strand of work ranging from the seminal work of Kalecki (1945) and Simon et al. (1977) to more recent contributions such as Bottazzi and Secchi (2006) have approached the determinants of firms' demographics through “island-models” in which the growth of each firm is studied in isolation and driven by exogenous shocks. Klepper and Thompson (2006) provide deep micro-foundations to such approaches by focusing on the development of sub-markets. It is also worth pointing out that Gabaix (1999) has adopted a similar approach to explain the size distribution of cities.

Firms' demographics have also been investigated within the general equilibrium framework, from a more systemic perspective. The pioneering contributions of Hopenhayn (1992) and Ericson and Pakes (1995) consider the linkages between firms' production and entry and exit decisions at the industry level. They investigate the optimal organizational response of an industry with respect to productivity shocks (Hopenhayn, 1992) and/or stochastic competition from inside and outside the industry (Ericson and Pakes, 1995). However, these contributions do not provide a precise characterization of distributional properties. This gap has been filled by a second series of general equilibrium contributions that have put forward innovation and growth as the key determinants of the inner organization of the industry. Klette and Kortum (2004) show that the optimal R&D response of firms facing (Poisson distributed) competitive risks and growth opportunities yields Gibrat's law for the growth of firms (i.e. growth rate independent of the size) and a logarithmic size distribution. Luttmer (2007) considers a model with monopolistically competitive firms whose productivity grows stochastically over time. He explains the formation of a scale-free distribution of firms' size through the difference between the trends of productivity growth for incumbent and entering firms. Rossi-Hansberg and Wright (2007) emphasize the role of the accumulation of industry-specific human capital in the emergence of scale-free distribution of firms' size. In particular, they show that scaling is more important in industries with large industry-specific physical capital. Their results are backed by empirical evidence on the fact that “*US sectors with larger physical capital shares exhibit significantly more scale dependence in establishment size dynamics and distributions.*”

Our approach retains the dynamic perspective of the “island-based” literature and the systemic perspective of the general-equilibrium literature. It is closer to the strand of literature à la Hopenhayn (1992) because it focuses on competition *per se* and does not require the introduction of aggregate growth to explain a wide range of stylized facts. The empirical results we obtain are nevertheless very similar. In particular, our emphasis on the role of competition is perfectly consistent with the observation made by Rossi-Hansberg and Wright (2007) that scale dependence increases with fixed costs.