Impact of Personal Fabrication Technology on Social Structure and Wealth Distribution: An Agent-Based Simulation Study

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The recent surge of the "Maker" movement (Anderson 2012) is largely driven by the increasing availability of the personal fabrication technology such as 3D printing (Lipson & Kurman 2013). Widespread diffusion and adoption of personal fabricators based on von Neumann style general purpose constructors are considered as one of the central possibilities of living technology (Bedau et al., 2010; Rasmussen et al. 2011). This is expected to cause a major shift of design and manufacturing power from large firms to individuals, in ways similar to how personal computers and information technology changed information production and dissemination in our society over the last few decades.

Personal fabricators occupy an interesting position in the network of goods and products from an artificial chemistry perspective (Dittrich, Ziegler & Banzhaf 2001). The whole manufacturing system in human civilization can be understood as a huge metabolic network in which reactants and catalysts are goods (raw materials and products) and fabricators (production tools ranging from human hands, hammers and knives to advanced computers and large-scale factories), respectively (Becker et al. 2013). In this context, the role of personal fabricators is close to that of general-purpose catalysts, such as ribosomes in biological systems. Such general-purpose catalysts tend to have high complexity and slow reaction rates, yet they can produce a great variety of complex products.

The emergence of ribosomes and gene-protein translation mechanisms in the history of life enhanced diversity, functionality and complexity of biomolecular machines significantly, clearly marking one of the major evolutionary transitions (Maynard-Smith & Szathmary 1997). This observation naturally leads one to ask the following question:

What kind of societal transition may occur due to the rise of personal fabricators?

This is not a trivial question to answer because of the differences between biological and socio-economical systems. Unlike biological cells, modern socio-economical systems are largely driven by individuals who have conflicting personal and financial interests and strategically determined behaviors imbedded in a marked driven economical system. Such behavioral complexities of anthropomimetic agents are often omitted in computational social simulations, though they would be necessary in order to capture relevant socio-economical dynamics.

To investigate the potential societal impact of the rapidly emerging personal fabrication technology, we developed an agent-based simulation of designing-manufacturing-economy dynamics. In this model, agents design and produce goods using other goods as materials based on their knowledge of manufacturing processes, and then trade the products with other agents, in order to maximize their own utility (largely determined by monetary profit). The system consists of two main components: (i) *the static universal product network* made of all n possible goods using m materials in different ways determined by their connections and (ii) *the dynamic economy* made of agents and their realized markets, which are where goods are actually traded.

The static universal product network represents the global set of all manufacturing processes possible (including not yet realized) in the simulated world. It is randomly generated using a heuristically designed algorithm as a bipartite network made of two types of nodes: reactants (raw materials and products) and reactions (production processes). Each reaction combines multiple reactants and produces another reactant at a certain rate. In this network, fabricators can be identified as catalytic reactants that do not increase or decrease in number through a reaction process.

Each catalytic reactant (fabricator) has its inherent complexity and utility values assigned to it. The complexity of a product is always bounded by the complexity of the fabricators and products used in its production process. Fabricators with high complexity, slow reaction rates but great universality (i.e., ability to catalyze a great number of reactions) represent general purpose personal fabricators. In contrast, fabricators with medium complexity, fast reaction rates and high specificity represent large-scale mass-production factories. Fabricators with low complexity, slow reaction rates and high universality represent primitive manufacturing tools such as hand tools. Agents are initially equipped with the fabricator with lowest complexity to start with.

The dynamic economy consists of agents and their markets. Each agent has the following properties: (1) amount of money it has, (2) inventory and price of goods they own (including fabricators), (3) utility associated with each product in the product network, and (4) the combined utility of all of the products in their inventory. At each time step, an agent randomly generates a finite number of possible actions (which goods to produce, which goods to purchase, etc.) and assesses
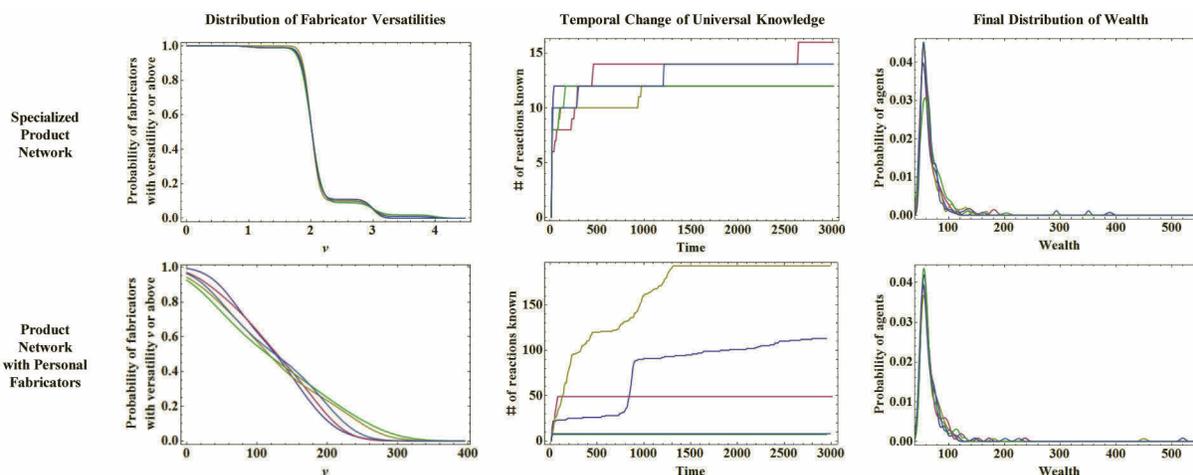
Figure 1: Simulation results. Results of five independent runs are shown in each plot. Left column: Complementary cumulative distributions of fabricators' versatilities. Top (across all columns): Results with a specialized product network without versatile personal fabricators. Bottom (across all columns): Results with a production network with versatile personal fabricators.

them to choose one that will increase its overall utility most as the next action.

Agents have partial knowledge about the universal product network (i.e., subgraph of the network), which is shared amongst all agents. At any given time step, there is a small probability by which an agent discovers (and implements) a new reaction in the universal product network and add this information to the communal knowledge base. This simulates gradual accumulation of innovations in society over time. An agent is only able to produce products that are included in the communal knowledge base.

Using the agent model described above, we conduct simulations with the abundance of personal fabricators in the universal product network varied as the experimental input. More specifically, we test two different scenarios of the universal product network: (1) a specialized product network where the fabricators' versatilities (i.e., number of products a fabricator can produce) are quite low and homogeneous (Fig.1, top left), and (2) a product network where the fabricators' versatilities show a fat-tail distribution in which some fabricators can produce a great number of different products (representing the possibility of personal fabricators; Fig. 1, bottom left).

Our preliminary simulation results show an interesting difference in technological development between the two scenarios, as shown in Fig. 1 (middle and right). With the specialized product network, after 3,000 time steps, agents tend to discover only a small number of reactions (top middle). In contrast, with the product network with versatile personal fabricators, agents can discover an order of magnitude larger number of reactions (bottom middle), and they often achieve innovative breakthroughs (seen as rapid increases of curves). The final distributions of wealth are found to be similar in both conditions, however (bottom right).

We note that our simulation is still preliminary and limited in several aspects. First, to include the key components the complexity of the current simulation is quite high as it implements a number of assumptions involved in designing-manufacturing-economy dynamics. This makes it rather difficult to explore, calibrate and validate experimental settings.

Second, the economic rules currently used to determine the prices of goods are simplistic and could be improved by implementing more well-established economics theories. Third, the incentives for agents to discover and produce new innovative products are currently given by inherent utility assigned to each potential product, which may not be a valid assumption to make. We are currently working on a simplification, revision and more thorough validation of our simulation.

References

Anderson, C. (2012). *Makers: The New Industrial Revolution.* Random House Business Books.

Lipson, H., & Kurman, M. (2013). *Fabricated: The New World of 3D Printing.* Wiley.

Bedau M.; Hansen, P.G.; Parke, E. & Rasmussen, S. (2010) *Living Technology: 5 Questions*, Automatic Press / VIP. p 236

Rasmussen, S., Albertsen, A., Fellermann, H., Pedersen, P. L., Svaneborg, C., & Ziock, H. (2011). Assembling living materials and engineering life-like technologies. In *Proceedings of GECCO 201)* (pp. 15-20). ACM.

Dittrich, P., Ziegler, J., & Banzhaf, W. (2001). Artificial chemistries-a review. *Artificial life, 7*(3), 225-275.

Becker, T., Meyer, M., Beber, M. E., Windt, K., & Hütt, M. T. (2013). A comparison of network characteristics in metabolic and manufacturing systems. In *Dynamics in Logistics* (pp. 141-150). Springer Berlin Heidelberg.

Maynard-Smith, J., & Szathmary, E. (1997). *The Major Transitions in Evolution.* Oxford University Press.