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Matthias Müller

An Agent-Based Model of Heterogeneous Demand

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With a foreword by Prof. Dr. Andreas Pyka

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Matthias Müller
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Foreword

Published in 1982, probably the most quoted book in innovation economics is *An Evolutionary Theory of Economic Change* by Richard Nelson and Sidney Winter. Today, it is considered as a cornerstone for modern evolutionary economics and thirty-four years later, evolutionary economics has created numerous insights addressing economic development and innovation-driven change.

Against this backdrop, it is astonishing that the relationship between innovation and demand has been largely neglected and that innovation economics has been often limited to the analysis of supply side effects exclusively. Instead, this issue was addressed first by innovation politics, applying not only public procurement but also subsidies for consumers as an effective tool for fostering innovation. Important examples of this are the renewable energy act securing guaranteed prices above market prices for sold electricity of photovoltaic systems or subsidies for electric vehicles in Germany. It is without doubt that new innovations require consumers who are willing to spend a part of their incomes. With this we see a first important link in the co-evolutionary relationship between income and technological development. At the same time, however, we have to consider that the particular demand of heterogeneous consumers is an important key for the diffusion of innovations. The demand of consumers determines which innovations will be successful and how successful innovation processes should be structured. At an extreme, we see that consumers often also actively participate in innovation processes co-designing innovations in so-called user-producer-relations. Although the debate between a technology-push or demand-pull perspective dates back to the late 1970s and has resulted in favour of a balanced view as noted for example by Nathan Rosenberg, today, the demand side is still somewhat neglected within innovation economics. In his thesis, Matthias Müller addresses this research gap and analyses the multi-faceted interplay of demand and innovation processes especially for the sectoral development based on a theoretical model. Central to his work is an agent-based computer simulation of innovation and demand. Matthias Müller's research represents an important milestone and, at the same time, the basis for further research on this issue relevant not only from a theoretical perspective but also for the application of a new understanding of the complex relationship between innovation and demand.

Prof. Dr. Andreas Pyka

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Symbol	Description
$\overline{K_j}$	firm j's knowledge stock
$K_{i,j}$	knowledge unit K_i of firm j
$C_{1,\dots,n}$	firms' capabilities
$A_{1,\dots,n}$	firms' abilities
$E_{1,\dots,n}$	firms' expertise levels
IH_j	knowledge pieces of firms unused in a particular production process
v_X^i	measure of product X in respect of characteristic i
$A_{k,j}$	set of characteristics of product k of firm *j*
$M_{A_{k,j}}$	mapping function of product k
$C_{k,j}$	product characteristics of product k of firm j
$D_{k,n}$	demand of consumer n for product k
p	global parameter to determine the level of heterogeneity of demand in the simulation
$\Delta(A_{k,j}, D_{k,n})$	Hamming distance between the set of characteristics of product k and the demand of consumer n for this product k
φ_j	firm j's market share
h^r	threshold for radical research
h^i	threshold for incremental research
s_N	sensitivity of consumer
$v_i = (v_{i,c})$	knowledge vector of agent i with knowledge categories c
$\bar{v}$	knowledge stock of all agents over time in the barter trade model

$P(k) \sim k^{-\gamma}$	probability *P(k)* that a node in the network is linked with *k* other nodes
w	probability that links within a regular ring network lattice are randomly redistributed
α_i	absorptive capacities of agent i
ω_i	an agent i's realitive position in the network indicated by the degree difference between i and his direct partners
ε	number of randomly chosen informed consumers
γ	individual importance of product characteristics
δ	ratio between consumers not considering negative product characteristics and responsible consumers

1 Introduction

1.1 The Invention of the Wheel

Today, the word innovation is something everybody knows. It is one of those buzz words which one encounters in many different ways and occasions. Firms advertise even slight changes as brand new innovations and are never tired of emphasising their innovative behaviour. Even politicians recognise the importance of at least mentioning *innovation*, and policies to stimulate innovation have become an important topic for the government. Also the European Commission, for example in its *Innovation Union – A Europe 2020 initiative*, calls for innovation as a central element in its attempt to stimulate the European economy:

> "We are facing a situation of 'innovation emergency'. […]. Thousands of our best researchers and innovators have moved to countries where conditions are more favourable. Although the EU market is the largest in the world, it remains fragmented and not innovation-friendly enough." (European Commision 2016)

Facing this claim, it is remarkable how little we know about innovation and how and why they are created. Until the early 19th century, economic growth was believed to be achieved solely via an increased use of production factors such as capital or labour. Due to the seminal work of, for example, Schumpeter (1912, 1942) and Robert Solow (1956, 1957) this view has changed today and innovation perceived as technological progress has been identified as one of the main forces that drives economic growth and prosperity. But do we really understand the innovation process in all its complexity?

Looking back into human history, it becomes clear that innovations shape human life in every imaginable way. Starting with the invention of the wheel, which can be dated back to the early Bronze Age, the list of substantial innovations seems endless. Animal powered ploughs, the steam engine, the combustion engine, electric power, the first airplanes, and modern communication devices such as smartphones are just a few examples of important milestones in human development. Each of these represents a substantial change not only for the economy but also for every man's life.

Determining the most important invention of all time may sound impossible. Putting forth the ideas of Alfred North Whitehead, the answer may also be simple: it is the method of the invention itself. What Whitehead suggests in his famous book from 1925 *Science and the modern world* about the inventions of the nineteenth century, is a fascinating and significant insight into the heart of the innovation process. Instead of evaluating the impacts or the alleged complexity of

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different innovations, Whitehead put forward the idea that the way innovations are created changed by the end of the 19th century. He states that the process of inventing before this transformation was slow, unconscious, and unexpected, and it became quick, conscious and expected (Whitehead 1975, p. 120).

What Whitehead hereby acknowledges is nothing less than the inherent complexity of the invention process (and with that: of the innovation process) and the revolution of how we deal with it. Although in retrospect some innovations may seem to be the result of single Eureka moments of single inventors, it would be a false conclusion that innovation takes place in an isolated world. The wheel for example, ranking first in the above list of inventions, was not simply the humble result of a single inventor. It was one of the first inventions that was not inspired by the natural world (LaBarbera 1983) and was the result of the complex interplay of different technologies, knowledge, and other factors of that time, although it is sometimes unjustly seen as simple and trivial, today.

Surprisingly, the first records of wheels in use for transportation purposes show that wheels weren't invented until 3,500 a. Chr., which is relatively late in human history, considering the technological capabilities of that time and other prominent inventions dating before the wheel. One clear reason why the wheel was invented so late in human history is that metal tools were needed to achieve the accuracy to guarantee a smooth and frictionless combination of wheels and axles. Using stone tools to shape perfect circular wheels and drill holes for the axles would have been a hassle. Producing the right metal tools such as drills, saws, and grinding tools, however, requires the knowledge and the technology to shape and make use of metal that meets the requirements for that purpose. This in turn requires an expertise in identifying the right raw materials, i.e. stones containing metal ores, producing coal, ovens to achieve the right temperature, and eventually the knowledge of how to combine the right ores to produce bronze. In other words, the wheel was not invented earlier because it was built from a large set of knowledge and previous inventions. In fact, with this background, the invention of the wheel appears incredible for its time.

Today, the complexity behind the innovation process, the interplay of different technologies, knowledge and the versatility of actors involved is increasingly recognized, not only in the broad field of economic science, but also by politicians and policy instruments. Without this *new art of invention* of the 19th century, as Whitehead puts it, modern inventions were simply impossible. What changed during the 19th century was the way science and technology was perceived and how the people of that time managed the complexity of the scientific process. This lead to a new and ground-breaking professionalism in science and the broad establishment of universities and other research institutes designed to

systematically create new scientific knowledge and methods and thereby made complex inventions possible (Whitehead 1975).

There is, however, a second reason for the late invention of the wheel and this reason is easily neglected. We have to consider the increasing demand for the efficient transportation of goods and commodities at that time. While the back of an animal such as a horse, donkey or an ox may be sufficient for bridging short distances, increasing trade of goods around the world and thus intensifying the establishment of common trade routes created an enormous demand for that invention for the first time in human history. Second, the story would be incomplete if we neglected an additional factor which triggered the invention of the wheel as a means for transportation. In fact, we have to consider that the invention of the wheel as a means for transportation was not the first invention of the wheel. Centuries prior to that, simple forms of wheels appeared in pottery, enabling potters to easily produce simple but effective containers to carry water, nutrition, etc. Driven by the large demand for these products, the technology of producing pottery wheels quickly diffused and at some point was improved so that wheels for transportation were also possible. In other words, one might speculate that the demand for pottery created the necessary basic prerequisite for the invention of the wheel.

The demand side, e.g. users and consumers, is an important element in the whole picture of the innovation process. Unfortunately, it is too often neglected or in the best case oversimplified in economics. Admittedly, it would be false to state that the demand side and the role of consumers have not been considered at all. Instead, we have to be more precise and ask *how* it has been considered as an element of the innovation process.

Until the middle of the 20th century the focus of the scientific discourse was on the question of whether the demand side has effects on the innovation process. Today, after a fruitful discussion in the literature, the debate branched into several aspects dealing with the question of how the demand side influences the innovation process. The well-known concept of user-innovation by Eric von Hippel (1976, 1988) is just one example in which consumers are appreciated as important actors in the innovation process. Following this idea, consumers sometimes act as innovators themselves, creating novel solutions for the particular and individual needs they have. However, by far the larger portion of work on innovation and technological change is concentrated on supply-side dynamics (see for example Adner, Levinthal 2001, Coombs 2001, Witt 2001a, Harvey et al. 2001, Andersen 2007, Ciarli et al. 2008, Nelson, Consoli 2010).

One possible explanation for this fact lies in the origin of modern innovation economics theory. Innovation as an economic concept can be traced back to the work of Joseph Alois Schumpeter, who stands with his work in-between the work