2 The Role of Consumers in Innovation Economics

This chapter describes the theoretical foundation of the simulation model carried out in the later chapters of this dissertation. We aim to show how demand side aspects have been included in the economic literature on innovation in the past and how they are included today. Additionally, this chapter also describes the fundamental aspects of the so called evolutionary economics approach which will be used as a framework for the model carried out in the later chapters of this dissertation.

We start in section 2.1 with a detailed description of how the demand side has been included in the literature on innovation. In more detail, this section discusses three well-known classes or generations of innovation models, each of which, representing fundamentally different perspectives on innovation. In section 2.2 the main characteristics of the evolutionary economics theory are discussed. This discussion also serves as a basic framework for the simulation model elaborated in the later chapter of this dissertation. Finally, section 2.3 outlines today's view on the role of the demand side for innovation, describing related concepts and models from literature.

2.1 The Neglected Demand Side

The following section discusses the relevance of the demand side for the study of innovation by giving insight to three fundamental different perspectives on innovation. While the importance of the demand side has long been acknowledged in various economic fields, its particular role for innovation has long been under great debate. We start in subsection 2.1.1 with some early contributions stressing the concept of the linear innovation model. Based on this, subsection 2.1.2 describes the so called demand-pull model. Finally, subsection 2.1.3 explains the basic ideas behind multidimensional innovation models.

2.1.1 The Linear Innovation Model

As the basis for the later analysis, let us start with a brief look into the history of economists' thoughts on innovation and the demand side. It would be too easy to state that the demand as an important factor is something completely new for the analysis of innovation or in economic science in general. On the contrary, one is tempted to say that the demand side has always been part of the story, the question is in which way it has been considered.

Let us start with a fascinating contribution by Adam Smith who in his famous book: *An Inquiry into the Nature and Causes of the Wealth of Nations* describes the important role of the division of labour for economic growth (Smith 1776).

M. Müller, *An Agent-Based Model of Heterogeneous Demand*,
DOI 10.1007/978-3-658-18722-4_2

Although Smith recognizes science and research as a main driver of growth (Knell 2012), he also sees the market size as a crucial because limiting factor:

> "As it is the power of exchanging that gives occasion to the division of labour, so the extent of this division must always be limited by the extent of that power, or, in other words, by the extent of the market." (Smith 1776, p. 31)

He continues and describes for example the particular role of geographical structures and the distribution of population as crucial factors for the division of labour. Smith notices that in the rural and scattered areas of Scotland "every farmer must be a butcher, baker, and brewer, for his own family" in which case there is no place for division of labour (Smith 1776, p. 32). Smith hereby clearly stresses the role of demand as a necessary condition for technological developments which becomes also clear if we look in more detail on the causal loops of economic development.

Following Smith, an increase of market demand fosters the division of labour, sectoral specialisation, and the accumulation of knowledge. This in turn leads to an increased competition between producers and a decrease of prices, at least in the long run. This leads to an increased productivity and revenues which, in turn, increase the market size and demand (Smith 1776, p. 31, see also Knell 2012, Antonelli, Gehringer 2015 for a detailed discussion on this issue). A diagram of this causal loop is shown in Figure 1.

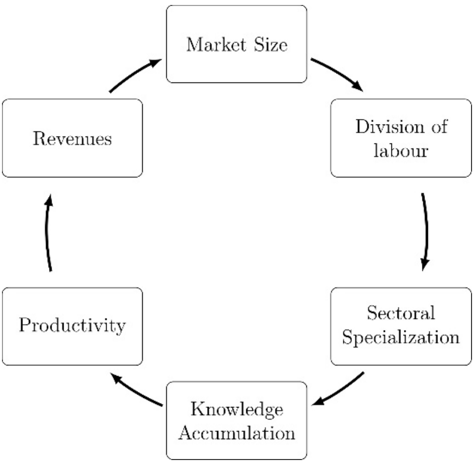

Figure 1: Smith's Circular Growth (Source: own illustration based on Antonelli, Gehringer 2015).

So, although Smith never particularly stresses the role of demand on innovation, we still see with Smith a general acknowledgment of the size of markets as a driving force for economic development. In a similar vein as the studies by Smith, also other scholars focus their analysis of economic processes on the role of demand. Probably the most famous author in this respect is John Maynard Keynes who focused in his studies deliberately on the role of *demand* which was in contrast to the dominant perspective in economics at this time (see for example Geiger 2015).

In this sense, it is interesting to note that the focus on the demand side has not been adopted by Joseph Alois Schumpeter. Instead, Schumpeter (1912, 1942) focused in his work on the role of monopolists and entrepreneurs stressing that entrepreneurs discovers (new) ideas so far untried and introduces them into the economic realm, leading to *creative destruction* (Coombs et al. 1987). Interestingly, although Schumpeter does acknowledge the influence of consumers' preferences on the production decision of firms, he considers them as static (Knell 2012). The consumer side of the market is driven by routine behaviour and limited foresight, which in turn give the entrepreneurs the role to convince the consumers to change their preferences (Andersen 2007).

From that we can conclude, it would be a false conclusion that Schumpeter refuses any particular role of the demand side. Instead, he as Smith before him recognises the importance of the size of the demand as a factor determining the profitability of innovations. With this, the demand influences the innovative activities of entrepreneurs. However, if asked for the source of innovation Schumpeter clearly would advocate the role of entrepreneurs, large monopolistic or oligopolistic firms.

This passive view on the demand side is also expressed in the famous and well-known linear innovation model. The linear innovation model is something very prominent in economic science and can be traced back directly to the ideas and the work of Schumpeter (Godin 2006). As a matter of fact, it is highly doubtful that there is a student who has not seen it, or can avoid it in his studies. It is a model of a theory, demonstrating and underlining that innovation is indeed a process with several definable steps which are embedded in a multifaceted innovation process (Godin 2006).

Early types of linear innovation model, can be traced back to the work of Price and Bass (1969) or Langrish et al. (1972), others say that the origins go even back to Bush (1945) *Science: The endless frontier* (see also Godin 2006 for a great overview on the history of the linear innovation model). In the literature we find a wide range of different types and forms of the linear innovation model in the literature. In principle, we can identify in linear innovation models three separate building blocks: the nature of the sources of innovation, the innovative process, and the effect of innovation (Kline, Rosenberg 1986, Rothwell 1994, Edgerton 2004, Godin 2006).

In its original form, the linear innovation model follows the innovation process as introduced by Schumpeter. A common composition of such a model can be seen in Figure 2. In this case we differ between 5 steps which run sequentially, i.e. basic research, applied research and development and ends with production and diffusion (see for example Godin 2006). In this model, the two elements basic research and applied research act as a source for innovation. The innovation process then is described via the development and production. Finally, the effect of innovation is seen in the diffusion of the innovation.

Figure 2: The Linear Innovation Model (Source: own illustration based on Godin 2006).

The exact composition of the elements of the linear innovation has long been under great debate. For example, it is questionable to what extend we can make a clear cut between basic and applied research. The key characteristic of this model, however, remains. It is a stepwise process, going sequentially from one end to the other, and hereby putting special emphasis on research and development as the source of innovation reflecting Schumpeter's perspective on innovation.[4] The demand side has no particular role from this perspective. At the best, this early perspective considers the demand side as something passive and pale.

2.1.2 The Demand-Pull Modell of Innovation

Interestingly, it was not until the seminal work of Jacob Schmookler (1962, 1966) and Nicholas Kaldor (1966, 1972) that the demand side has been (re-) recognised as one of the key factors of innovation and economic development. Although Schmookler and his studies are generally credited to be the reason for the new momentum in the debate on the role of the demand side, there is also the work of Nicholas Kaldor (1966, 1972), who contributed important insights in a post-Keynesian framework analysis. So for example in (1975, p. 895) Kaldor stated:

> "[…] economic growth is demand-induced, and not resource-constrained - i.e. that it is to be explained by the growth of demand which is exogenous to the industrial sector' and not by the (exogenously given) growth rates of the factors of production, labour and capital, combined with some (exogenously given) technical progress over time."

4 This is also the reason why Schumpeter often is considered as the intellectual father of this model (Godin, Lane 2013).

Kaldor emphasises in his papers multipliers and accelerator effects to support the idea that increases in public expenditures, able to support the expansion of aggregate demand, have positive effects on productivity growth, output and eventually investments (Antonelli, Gehringer 2012). Additional investments, in turn, were expected to fasten the diffusion of technological innovations. In a similar vein as in Figure 1, Figure 3 presents the Kaldorian demand-pull mechanism as a circular process of cumulative causation:

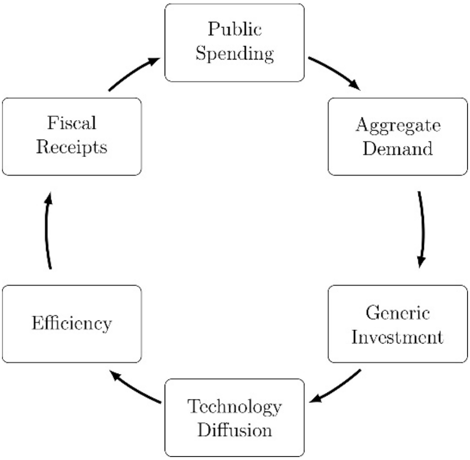

Figure 3: The Kaldorian Demand-Pull Mechanism (Source: own illustration based on Antonelli, Gehringer 2012).

Unfortunately, the model of economic growth by Kaldor did not receive much attention at its time. Instead, it was Schmookler, who gave new momentum to the story by contributing one of the first empirical studies on the relationship of demand and innovation. Unsatisfied with the linear view of a supply-oriented focus on the innovation process, Schmookler (1962, 1966) analyses empirically the connection between demand and innovation studying different industries of the US economy.

In his paper *Economic Sources of Inventive Activity* (1962) Schookler uses patent data to analyse the relationship between demand and innovation[5] in the railroad industry. His results show that peaks in patenting activities indeed lag behind peaks of production of commodities, from which he concluded that innovation can no longer be regarded as independent variable as it was done so far. He concluded that the influence (upon innovation) of the latter (unfolding

5 Technically speaking, Schmookler, thus, does not directly measure the effect on innovation but on inventions.

economic needs) has been substantial, at least in established industries (Schmookler 1962, p. 20). Schmookler's explanation for this fact is simple, yet, convincing:

> "[…] the incentive to make an invention […] is affected by the excess of expected returns over costs. Scientific progress may reduce expected costs and so increase the probability that a given invention will be sought and made. However, every invention represents a fixed cost, and the expected benefits from it vary with circumstances." (Schmookler 1962, p. 19)

In Schmookler's perspective, the size of the potential market represents a necessary trigger for firms to innovate. The potential market determines the potential benefits of an innovation and directly influences the innovative behaviour of profit seeking firms. In other words, it would be highly doubtful that firms engage in any costly innovative activity without the expectation to gain profits from that innovation. In fact, consumers are the driving force for any innovation activity, steering firms towards what they want.

Schmooklers studies, but also famous studies such as *Project Hindsight* by the United States Department of Defense (Sherwin, Isenson 1967) and many others (see for example Mowery, Rosenberg 1979, Rothwell 1977, Coombs et al. 1987 for an overview) led to a second class of sequential innovation models, i.e. demand-pull models which are strongly related to previous linear innovation models.[6] Early versions of a demand-pull model emerged in literature in the late 1970s. They reflect the upcoming debate in the 1960s on the influence of the demand side and are actuated by the findings of Schmookler (Godin, Lane 2013). For example in (Rothwell, Zegveld 1985) we find a diagram of the demand pull model as pictured in Figure 4. In this case the source of innovation clearly lies in market needs. The development and manufacturing, instead, can be seen as the process of innovation. Finally, the element sales represent the effect of an innovation.

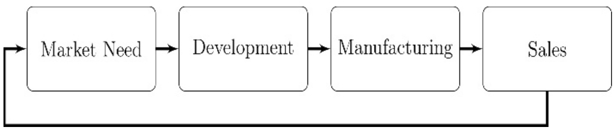

Figure 4: The Demand Pull Model (Source: own illustration based on Rothwell, Zegveld 1985).

Although the demand-pull model shares the sequential perspective with the former linear innovation model, it still represents a major shift in the underlying perception of the innovation process. It puts emphasis on the market needs as the

6 The demand-pull model sometimes also is labeled as *Market-Pull* or *Need-Pull* model (Rothwell 1992).

nature of the sources of innovation instead of basic science or research and development as in the previous form. Here it is argued that most critical for innovations are need-pull forces expressed in opportunities, pulling from peoples' needs (Godin, Lane 2013). In other words, following this perspective the demand side is something active which represents a huge change in thinking for many scholars from that time.[7] Unfortunately, the demand-pull model was only for a short period in the focus of scientific literature and has been replaced, together with the technology-push model, by the upcoming multidimensional innovation models in the 1980th (Rothwell 1992, Godin, Lane 2013).

The main reason for this change was the dissatisfaction with the sequential nature of both models. The critique that innovation is not a linear process, however, was nothing new. So did for example already Price and Bass (1969, p. 802-803) note:

> "[…] innovation is often viewed as an orderly process, starting with the discovery of new knowledge, moving through various stages of development, and eventually emerging in final, viable form. According to this 'linear' model, innovation seems to be a rational process […]."

Analysing and reviewing three studies on innovation Price and Bass yet come to the conclusion:

> "The studies reviewed here indicate that the 'linear' model is not typical. One appreciates the nonrational nature of the innovative process when one notes that the more novel the invention is, the less orderly and predictable is the process." (Price, Bass 1969, p. 803)

Additional points of critiques on the existing models of innovation were for example the distinction between basic (scientific) and applied (technological) research, and how the former informs the latter and the connection between transfer of new scientific knowledge into technology and commercial innovations (Balconi et al. 2010).

In summary, the demand-pull model introduced a new perspective to the question about the main drivers of innovation (see Coombs et al. 1987 for a good overview about the four central question about the origin of innovations). The vast range of critics led to an intense debate which was calmed by the idea that the question for an ultimate source of innovation does not lead to any further insights. Instead, scholars began to understand that innovation has a strong systemic character (see for example Fagerberg 2004) in which multiple elements are in

7 To put it to an extreme, the demand side in the demand-pull model still represents something quantitative: more demand means more innovation. Admittedly, a more qualitative view on the causal interdependencies between demand and innovation is also in the demand-pull model missing.

strong interdependence. This understanding quickly led to the development of the third generation of innovation models: multidimensional models of innovation.

2.1.3 A Multidimensional Perspective on Innovation Processes

Since the seminal work of Schmookler, a series of empirical studies have tried to support the hypothesis by Schmookler (e.g. Sherwin, Isenson 1967, Myers, Marquis 1969, Langrish et al. 1972, Gibbons, Johnston 1974, Gibbons, Gummett 1977, Scherer 1982, see also Andersen 2007) while others refused this perspective and viewed the activities and internal capabilities of firms as the primary drivers of innovation. The two most common critiques in this respect have been that (1) Schmookler deals with invention rather than innovation and (2) that demand-pull has often been interpreted in terms of need-pull which is a concept too broad to allow for falsification (see for example Mowery, Rosenberg 1979, Walsh 1984, Kleinknecht, Verspagen 1990).

As a preliminary result of this debate between proponents of demand-side arguments and their opponents, Mowery and Rosenberg (1979) state that this debate is misleading and that both the demand and the supply side appear to simultaneously play crucial roles:

> "Rather than viewing either the existence of a market demand or the existence of a technological opportunity as each representing a sufficient condition for innovation to occur, one should consider them each as necessary, but not sufficient, for innovation to result; both must exist simultaneously."

Following Mowery and Rosenberg successful innovation emerge from the fruitful interaction between demand-pull and technology-push effects and consequently no dominant factor can be identified (Mowery, Rosenberg 1979).[8] In other words, while without doubt the demand side plays a major role in shaping the direction of scientific progress, it does so within the changing limits and constraints of a body of scientific knowledge (Rosenberg 1974). In a similar vein, also Giovanni Dosi (1982, 1988a) sees the demand side as in important factor within the concept of technological paradigms:

> "The evidence on market-induced innovative activity […] may indeed be consistent with our model […]. This process, however, relates much more to normal technology than to discontinuous technological advances." (Dosi 1982, p. 159)

8 Admittedly, although the appeasing simultaneous recognition of supply-side and demand-side is generally attributed to Mowery and Rosenberg (1979), already Schmookler (1966, p. 11) considered that: "Without wants no problem would exist. Without knowledge they could not be solved".

This shift in the understanding that innovation is not an orderly stepwise and sequential process with a beginning and an end led to the development of so called multidimensional models.[9] As an example, we briefly discuss the structure of the famous chain-linked model by Kline and Rosenberg (Kline 1985, Kline, Rosenberg 1986).

The chain-link model is one of the first representative examples of the class of multidimensional models which are characterised by interactions and feedback loops among all the factors involved in the process of innovation. Multidimensional models, therefore, avoid the question for an ultimate source of innovation. As also Kline (1985, p. 44) puts it:

> "In looped processes, every cause becomes in due time an effect, and every effect becomes in due time a cause. The distinction between pushes and pull loses all meaning."

The key issue here is that in contrast to the two linear models discussed so far, the chain-link model by Kline and Rosenberg manages to combine the mutual existence of demand-pull and technology-push effects in the innovation process. With this a clear shift in the debate about the role of the demand side becomes evident, while previous research focused mainly on identifying the main causes for innovation. The work of for example Mowery and Rosenberg (1979), Kline (1985), Kline and Rosenberg (1986) redirected the debate to the qualitative interdependence between all factors. This opened the discussion for questions not *if* demand is important for innovation, but *how* it is and how innovation is important for demand, stressing the systemic character of the innovation process (see also Fagerberg 2004).

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9 Multidimensional models also go under the terms iterative, interactive, recursive, systemic etc. Some important examples are for example the *Multidirectional model* (Pinch, Bijker 1987), *Neural net model* (Ziman 1991), *Coupling model* (Rothwell 1992), *Interactive model* (Newby 1992) and *Linear-plus model* (Tait, Williams 1999). See also Godin and Lane (2013) on this issue.

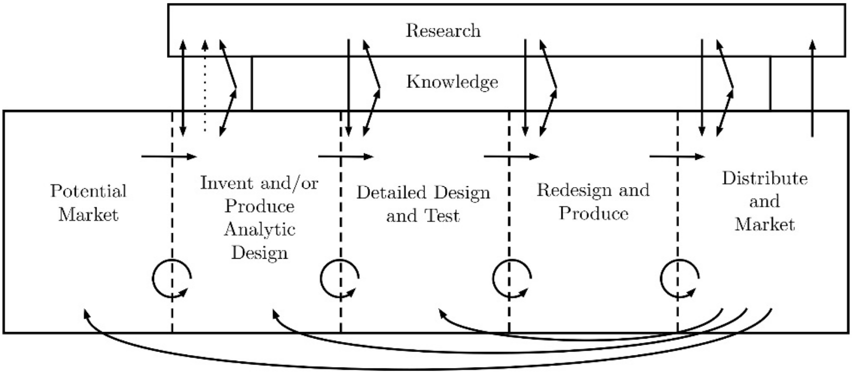

Figure 5: The Chain-Link Model (Source: own illustration based on Kline, Rosenberg 1986).

The chain-linked model by Kline and Rosenberg (see Figure 5) consist of seven elements embedded in a system without a clear and defined order:

- Research
- Knowledge
- Potential market
- Invent and/or produce analytic design
- Detailed design and test
- Redesign and produce
- Distribute and market

In their model, Kline and Rosenberg consider several feedback loops and couplings between the elements. Additionally, they identify not one but five major paths of activity (see Kline, Rosenberg 1986 for a detailed discussion about each path). So for example one path consists of starting with the potential market, ending up with the distribution. However, other paths are possible and can have different sources and elements of the system. For all of them, Kline and Rosenberg considered the possibility of several feedbacks and loops which are indicated by the various arrows in Figure 5. These feedbacks and loops illustrate that no clear sequential order is in action and correspondingly there are no such things as the source or the effect of innovation.

Kline and Rosenberg (1986, p. 291f) describe the role of the demand side in the chain-linked as follows:

> "A perceived market need will be filled only if the technical problems can be solved, and a perceived performance gain will be put into use only if there is a realizable market use. Arguments about the importance of 'market pull' versus 'technology push' are in this sense artificial, since each market need entering the innovation cycle

> leads in time to a new design, and every successful new design, in time, leads to new market conditions."

In other words, in the multi-dimensional model by Kline and Rosenberg the demand side and the supply side are in a coevolving relationship. Although some authors may criticise this ambiguity[10], the coevolution of demand and supply today is widely excepted, yet, underexplored (see for example Saviotti, Pyka 2012). Well-known approaches to get a in depth understanding on the relationship are for example the concept of democratizing innovation by Eric von Hippel (1976, 1988) or the wide field of studies about the diffusion of innovation which will be explained in more detail in section 2.3. 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).

Summing up this section's findings, the way the literature considers the demand side and its effect on innovation considerably changed over time and was always driven by a fruitful discussion. The debate led to an understanding based on which the demand and the supply side are in a mutual relationship with different causal processes. The analysis of this dynamic relationship, however, requires both: a theoretical and a modelling framework which allows us to systematically analyse the mutual interaction between two too often isolated elements of the complex economic system.

2.2 An Evolutionary Perspective

The term evolutionary and its connection to economy theory has long been under great discussion and unfortunately has not achieved at a final consensus yet. For the beginning, let us start with a broad understanding from Boulding (1991, p. 9) who says that: "evolutionary economics is simply an attempt to look at an economic system […] as a continuing process in space and time". Although this definition may convince through its simplicity and parsimony, there is more to the evolutionary approach which is relevant and makes the evolutionary perspective the right approach to analyse innovation processes.

Instead of a broad agreement, today, the debate on what evolutionary economics has spread into several different groups, encompassing a variety of perspectives (Witt 2008, Hodgson 1999). In fact, the use of evolutionary as a term in economics is so wide-spread that for example Hodgson understands this as "a

10 For example Godin and Lane (2013, p. 24f), criticise that Kline and Rosenberg reduce the meaning of the demand side to what it was before the demand-pull model: "a single factor (among many) [...]".

matter of fashion" (Hodgson 1999, p. 128). Also Witt (2008) distinguishes based on the ontological stance and the heuristic strategy between the four distinct research strands: Universal Darwinism, Naturalistic, Schumpeterian and neo-Schumpeterian approaches which deserve to be labelled as evolutionary. This of course makes an exact definition of what evolutionary economics is and what the most important aspect in general are beyond the reach of this dissertation (see also Witt 2008 for an interesting questionnaire). However, we can capture three important elements of all evolutionary strands: an evolutionary theory is (1) dynamic, (2) historical and (3) self-transformation explaining (Witt 1993). In the following, we will briefly describe major cornerstones on the way towards an evolutionary economic theory, and thus explaining some of the main characteristics of the methodological framework of the model analysed in this dissertation.

Although the discussion about evolutionary economics gained momentum only since the second half of the twentieth century, the roots of an evolutionary perspective thinking can be traced back in economic histories to the late 19^{th} century and is found even amongst authors who are well known for their contribution to equilibrium theories (Dosi, Nelson 1994).

One of the first authors to deliberately mention evolutionary ideas in his work is Thorstein Veblen who already in 1898 demands in his paper "*Why is Economics not an Evolutionary Science*" an evolutionary economic theory (Veblen 1898, see also Hodgson 1998b for a detailed discussion on Veblen´s contribution). Highlighting especially the process characteristic of evolutionary economics, Veblen (1898, p. 375) frames his understanding of an evolutionary economics theory as follows: "Any evolutionary science […] is a close- knit body of theory. It is a theory of a process, of an unfolding sequence". And at a later part of his paper, he continues:

> "it appears that an evolutionary economics must be the theory of a process of cultural growth as determined by the economic interest, a theory of a cumulative sequence of economic institutions stated in terms of the process itself." (Veblen 1898)

Interestingly, already Veblen (1898) who is usually associated with other strands of economic theory, stresses the process character of an evolutionary economics theory. Veblen, however, has not been the only early contributor to the discussion. Evolutionary ideas can also be found at well-known economists such as Smith, Malthus, Marx, Penrose, Alchain and Marshall (see also Nelson, Winter 1982, Dosi, Nelson 1994, Hodgson 1999, Potts 2003).

One of the cornerstones for the development of an evolutionary theory of economics, and as some say maybe the biggest one (Fagerberg 2003, p. 11), can be credited to Joseph Alois Schumpeter and his work (e.g. Schumpeter 1912, Schumpeter 1942). Although Schumpeter avoided the term *Evolutionary* or *Evolution* in his early work (Witt 2008, p. 554), his unique interpretation of the economic development can only be considered a path-breaking contribution to evolutionary economics, which made him for almost 50 years the leading academic protagonist for the evolutionary approach (Fagerberg 2003).

In his famous book from 1912 *Theory of Economic Development* Schumpeter challenged the dominant view at this time that the cause for economic development can be found in exogenous factors. Instead, Schumpeter focused on endogenous drivers of economic development, providing the theoretical basis for a new paradigm (see for example Hanusch, Pyka 2007b for a discussion on Schumpeter´s contributions). Especially in his early work, Schumpeter highlights the role of the entrepreneurs as driving forces for evolutionary change, introducing the concept of the *creative destruction* as an inherent force that destroys every state of equilibrium (Kwasnicki 2007, Hanusch, Pyka 2007b). With this, Schumpeter as did Veblen beforehand, directly addresses especially the dynamic character of economic processes (Witt 2002), highlighting and emphasizing the role of innovation for economic processes. However, Schumpeter differs from Veblen in a sense that Schumpeter takes a perspective which Witt calls a dualistic ontology, treating economic and biological evolutionary processes as belonging to different, disconnected, spheres of reality (Witt 2008).

The next leap in the development of the evolutionary framework in economics can be seen in the work of Nelson and Winter and their synthesis of evolutionary ideas framing a comprehensive evolutionary approach in economics. A central motivation for Nelson and Winter's work rests on the limiting and unrealistic assumptions of what Nelson and Winter call traditional models (e.g. Nelson, Winter 1973) or, in more general, orthodox economic theory of their time (e.g. Nelson, Winter 1982). The notion of Orthodoxy as used in later work of Nelson and Winter widely refers to "a modern formalization and interpretation of the broader tradition of Western economic thought whose line of intellectual descent can be traced from Smith and Ricardo through Mill, Marshall, and Walras" (Nelson, Winter 1982, p. 6).

Nelson and Winter can be credited for at least three important papers to the discussion in the 1970s (Nelson, Winter 1973, Nelson, Winter 1974, Nelson, Winter 1975), which also constitute the underpinnings of their famous book *An Evolutionary Theory of Economic Change* from 1982. Inspired by the existence of an expanding literature that abandoned the at this time dominating models and their structural pillars and in favour of more sensitive and subtle formulations, Nelson and Winter criticized the restrictive and limiting setting of the orthodox framework (Nelson, Winter 1973). In particular, the authors rejected that the orthodox framework builds on the general assumption of maximisation as the key driver for firm behaviour within an analytical framework based on general economic equilibria (Nelson, Winter 1982).

Although Nelson and Winter (1982) base their description of an evolutionary economics theory also on an operational concept of the decision rules employed by firms, they strongly reject the idea of maximisation as the main driver for firms' behaviour. Instead, Nelson and Winter highlight the concept of so called routines to describe firms' activities. Routines in the sense of Nelson and Winter (1982, p. 14) cover:

> "[…] characteristics of firms that range from well-specified technical routines for producing things, through procedures for hiring and firing, ordering new inventory, or stepping up production of items in high demand, to policies regarding investment, research and development (R&D), or advertising, and business strategies about product diversification and overseas investment."

It is important to note that the contributions of Nelson and Winter cannot be seen isolated from the work of Schumpeter. In contrast, the connection of Schumpeter's work and the work by Nelson and Winter goes so far that the evolutionary approach carried out by Nelson and Winter can be seen a neo-Schumpeterian:

> "The influence of Joseph Schumpeter is so pervasive in our work that it requires particular mention here. Indeed, the term 'neo-Schumpeterian' would be as appropriate a designation for our entire approach as 'evolutionary' " (Nelson, Winter 1982, p. 39).

Nonetheless, we would go too far stating that the evolutionary economics approach in general is the same as neo-Schumpeterian approach. Given the wide range of different roots of evolutionary economics and thus, the different foci we agree with Hanusch and Pyka (2007a) and consider evolutionary economics as the basic framework in which neo-Schumpeterian economics puts a special focus on innovation.

In fact, there are some important differences between the original contribution by Schumpeter and the work of Nelson and Winter (see also Hodgson 1997, Witt 2002, Kwasnicki 2007 for a detailed discussion).[11] Nelson and Winter, in contrast to Schumpeter, include the general ideas of natural selection using a heuristic that makes metaphorical use of Darwinian concepts (Dosi, Nelson 1994, Fagerberg 2003, Witt 2008). In their famous book, Nelson and Winter (Nelson, Winter 1982, p. 9) promote the idea of general selection as the main characteristic of their approach:

11 Some authors differ in this context sometime between *the old evolutionary economics* and *the new wave of evolutionary theorists* (see for example Hodgson 1993, Andersen 2013, Fagerberg 2003).

> "Our use of the term 'evolutionary theory' to describe our alternative to orthodoxy […] is above all a signal that we have borrowed basic ideas from biology, thus exercising an option to which economists are entitled in perpetuity by virtue of the stimulus our predecessor Malthus provided to Darwin's thinking."

As Nelson and Winter note, evolutionary economics takes a process perspective on economic systems which stands in contrast to the equilibrium assumption of orthodox economic thinking[12]. Evolutionary economics in this context focuses on the explanation of the movement of an economic system, (as a whole or only parts of it) over time instead of analysing the dynamics of static equilibria (Dosi, Nelson 1994, Nelson, Winter 1982). This dynamic perspective of evolutionary economics, allows to consider path dependencies and the irreversibility of economic processes (David 1985, Arthur 1989, Hanusch, Pyka 2007a). The framework of the evolutionary economics approach enables us to study the versatile dynamics of the coevolution of the demand and the supply side.

The evolutionary economics approach also includes a sophisticated and more accurate description of economic actors and their behaviour. As for example Nelson and Consoli (2010, p. 666) note:

> "[evolutionary economists] share not only an interest in building a theory that deals with economic dynamics better than does neoclassical theory. They also share a set of beliefs in how to characterize and understand human behavior, and the behavior of human organizations, that leads them to reject neoclassical theory not only as a framework inadequate for understanding economic dynamics, but more generally as a deeply flawed theory of economic behavior in any context […]."

If we want to understand the mutual relationship between demand and supply, we have to consider demand side and supply side as more than just aggregated forces within the economic system. Instead, we focus on the entities behind these forces, e.g. consumers and firms which are of great relevance for a thorough and comprehensive understanding. Let us start with an aspect of evolutionary economics which is also considered at the later chapters and especially for the simulation model, namely the concept of heterogeneity. The evolutionary economics approach as for example described by Nelson and Winter breaks with the tradition and common practice to extrapolate the characteristics of a representative agent to an entire population (often referred to as *typological thinking*). In contrast, Nelson and Winter's *population thinking* looks at the social and economic consequences of interaction within population s of heterogeneous actors (Mayr 1959, Hodgson 1993, Andersen 2013).

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12 In this context, evolutionary economist often refer to so called *punctuated equilibria* (Hodgson 1997).

The aspect of heterogeneity is one of the most import aspects of evolutionary economics (Cantner, Hanusch 1999) and is in full contrast to the neoclassical approach and its concept of representative agents or representative firms (Marshall 1890). The concept of heterogeneity in evolutionary economics covers aspects such as: behaviour, attitudes or characteristics of agents (Cantner, Hanusch 2001). In its basic essence acknowledging the heterogeneity means recognizing economic actors as what they are: individuals facing *Knightian true uncertainty* (Knight 1921, Nelson, Winter 1982, Dosi, Nelson 1994).[13]

Building on this, Nelson and Winter include the concept of *procedural* or *bounded rationality* as described by Herbert Simon (1957, 1972) into their concept of evolutionary economics as a more elaborate theoretical perspective on how firms behave (Fagerberg 2004). Instead of perfectly rational behaving entities, firms in the perspective of Nelson and Winter behave guided by *routines* as heuristics and simple rules of thumb to tackle decisions. To evaluate the performance of these heuristics, firms apply a so called satisficing behaviour. So if a routine leads to an unsatisfactory outcome, e.g. the profits or sales fall below a certain threshold firms search for a new routines, which will eventually be adopted if it satisfies the criteria set by the firm (Fagerberg 2004).

As a result of the previous discussion, it is important to note that the perspective on evolutionary economics as proposed by Nelson and Winter, and which is today often seen as the main driver for the new momentum evolutionary economics gained today, cannot be considered as an independent and self-contained approach. Instead, it is the synthesis of different evolutionary scholars, and amongst them especially the work of Schumpeter and the growing demand for alternative approaches getting loose from the restrictive frameworks of orthodox models. As we have seen, the evolutionary economics approach offers a unique perspective both on a systemic level as also on an actor level. On a systemic level it breaks with the limiting equilibrium framework used by other concepts and capture a dynamic, process oriented view. As for example Hanusch and Pyka (2007a, p. 280) point out:

> "The outcome of evolutionary processes is determined neither ex-ante nor as the result of global optimizing, but rather is due to true uncertainty underlying all processes of novelty generation, and so allows for openness towards future developments - a feature of evolutionary theories which makes them ideal for analyzing innovation processes."

13 In contrast to situation of risks, true uncertainty refers to situations where not only the consequences of the set of possible alternatives are indefinable but it is also unknown which alternatives exist (Keynes 1937, Nelson, Winter 1982).

Second, evolutionary economics get rid of the oversimplified assumptions about economic actors which become necessary in equilibrium frameworks. Instead, within evolutionary economics it is possible to treat economic actors as individuals which are heterogeneous and only boundedly rational. This unique perspective offers a framework to analyse the mutual relationship between something heterogeneous and dynamic as innovation and demand.

2.3 The Role of the Demand Side Today

The debate of the last decades between the demand-pull and supply-push arguments has today not completely vanished. However, it is still true as many authors argue that demand-side effects on the innovation processes have been somewhat neglected or disregarded over the last decades (Coombs 2001, Witt 2001b). More specifically, Adner and Levinthal (2001) note that by far the larger portion of work on technological change is concentrated on supply-side dynamics. Harvey et al. (2001) stress the myopic concentration on the terms of market exchange characteristics of innovation studies, with its excessive attention to supply-side processes. The debate today has branched out into a number of sub-debates, each highlighting different aspects of demand in the innovation processes. With this, we see a more comprehensive analysis of the multifaceted relation between demand and innovation as for example Anderson (2007) points out. The following section discusses in some more detail the focus and contributions of some different branches.

Maybe the most prominent example in this respect has been the study of the diffusion of innovations. Early contributions to this field of study include the work of e.g. Gabriel Tarde and Friedrich Ratzel and Leo Frobenius in the late 19th century to the beginning of the 20th century. The empirical groundwork for the theory of innovation diffusion, however, was laid by Ryan and Gross (1943), who found that social contacts, social interaction, and interpersonal communication were important influences on the adoption of new behaviours (Valente, Rogers 1995). Today's interest in this field of study can be traced back in particular to the book *Diffusion of Innovation* first published in 1962 (Rogers 2010). For Rogers the diffusion of innovation means: "the process by which an innovation is communicated through certain channels over time". Rogers hereby refers to a fundamental aspect of innovation which already Schumpeter stressed (Schumpeter 1928, p. 378):

> "What matters […] is merely the essentially discontinuous character of this process, which does not lend itself to description in terms of a theory of equilibrium". In other words, innovations do not automatically diffuse through economic systems. Instead,

we have to consider that some innovations diffuse only slowly and some not at all. So the question emerges how and why do innovations diffuse?

Common elements of this interdisciplinary field of study and possible aspects to tackle these questions are: the innovation itself, the population of potential adopters and innovators and the flow of information about the innovation between manufacturers and adopters (Coombs et al. 1987).

One of the central assumptions of this framework is that adopters pass through a process of five stages: knowledge, persuasion, decision, implementation and confirmation which form the adoption decision of consumers (Rogers 2010). Building on this, it is possible to specify a large number of different factors determining the diffusion of innovations. These include innovator characteristics, particular innovation characteristics, characteristics of consumers and the characteristics of the information network between consumers and firms (see also Wejnert 2002).

One of the basic concepts within the field of diffusion research is the categorization of adopters in different adopter categories (Rogers 2010). In Figure 6 we show the resulting distribution measured by the time at which an individual adopts an innovation. Based on the propensity to adopt we can distinguish between five different adopter categories: innovators, early adopters, early majority, late majority and finally laggards. The boundaries of the categorization are generally defined by the average time an innovation is adopted ($\tilde{x}$) and the standard deviation (sd).

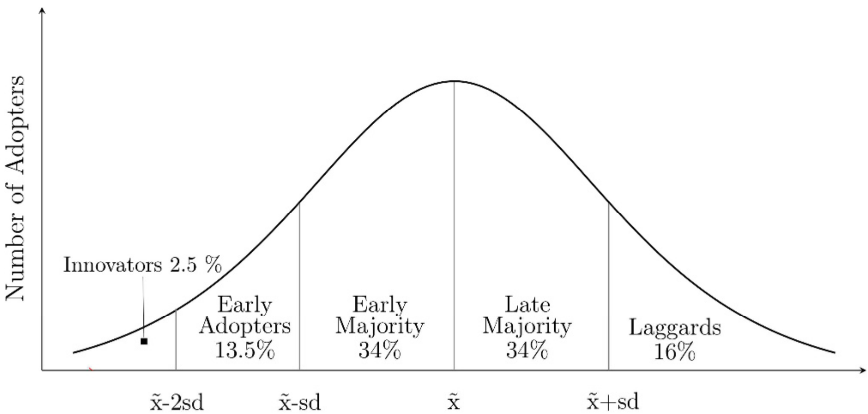

Figure 6: Adopter Categorization after Rogers (Source: own illustration based on Rogers 2010).

The studies in the field of innovation diffusion without doubt gave new interesting insights to the particular role of consumers (or to be more precise adopters).

However, it has often been criticised that potential adopters are too homogeneous in the analysis and the system itself behaves statically (Coombs et al. 1987, Kiesling et al. 2012). So for example, especially aggregated models (e.g. the famous diffusion model by Frank Bass (1969)) of the diffusion of innovations are based on the assumption that adopters are held homogeneous.

Today various individual-based diffusion models have extended the scope and consider the heterogeneity of adopters. For diffusion models, the heterogeneity of adopters is mainly modelled via heterogeneously distributed adoption thresholds to approximate varying propensities to adopt a new technology (Kiesling et al. 2012). Other important approaches include heterogeneity of demand through reservation prices (see for example Cantono, Silverberg 2009), communication behaviour (Rahmandad, Sterman 2008) or sociodemographic characteristics (see for example Dugundji, Gulyás 2008).

Insights from studies on the diffusion of innovation are also the basis for the famous lead-user approach by Eric von Hippel (1986, 1988). Combined with concept of so called user-innovation both aspects are generally summarised by the term *democratizing innovation*. Taking into account that consumers are heterogeneous in terms of their needs von Hippel describes the chance and importance of identifying so called *lead-users* who face needs months or years before the bulk of a marketplace encounters these needs and expect to benefit considerably by the new innovation. Although this concept is often used in marketing and management science it represents a without doubt important example for the shift in economists' minds. First, recognising consumers as important sources for information stands in contrast to the assumed passiveness of consumers underlying many economic approaches. Second, the lead-user concept also acknowledges heterogeneity of consumers, giving proof that the generalising approach of representative consumers neglects important aspects of reality.

Additionally, Eric von Hippel's user-innovation approach shows that the strict separation between consumers, i.e. economic actors purchasing innovations and firms as economic actors producing innovation not always holds true. Several studies show that consumers often take an active role in the innovation process and also become inventors themselves. Important examples are mountain bikes, several open source software products, the Go-Pro camera, Q-tips and many more. Unfortunately, this special form of invention and innovation got only little attention by the broad majority of innovation researchers so far (von Hippel 1988).

Another strand of important literature which gave great inspiration to this dissertation are agent-based models of innovation. In recent years a small number of models have extended the scope building on an evolutionary economics framework and analysing the relevance of different demand side aspects and the effects on their innovative process (see for example Andersen 2001, Saviotti 2001, Metcalfe 2001, Saviotti, Pyka 2004, Ahrweiler et al. 2004, Valente 2012, Babutsidze 2012, Lorentz et al. 2015 for important contributions). The following brief summary discusses some of them in more detail.

One interesting example for a model of innovation in a neo-Schumpeterian fashion is the so called SKIN (*Simulating Knowledge in Innovation Networks*) model family by Nigel Gilbert, Petra Ahrweiler and Andreas Pyka (shown for example in Gilbert et al. 2001, Ahrweiler et al. 2004, Gilbert et al. 2007). SKIN is an agent-based simulation platform in which a special focus is placed on knowledge and learning of firms. The model considers different strategies of learning of firms, i.e. incremental and radical, learning-by-doing but also networking.

The model draws on the concept of *kenes* (Gilbert 1997) to represent the individual knowledge stock of a firm. A firm j's knowledge stock $\overline{K_J}$ is represented as a set of knowledge units $K_{i,j}$ depicted as triples of the capabilities $C_{1,\dots,n}$, abilities $A_{1,\dots,n}$ and expertise levels $E_{1,\dots,n}$ of that knowledge unit (see also equation 1).

$$\overline{K_J} = \begin{pmatrix} C_1 \\ A_1 \\ E_1 \end{pmatrix}, \begin{pmatrix} C_2 \\ A_2 \\ E_2 \end{pmatrix}, \begin{pmatrix} C_3 \\ A_3 \\ E_3 \end{pmatrix}, \dots, \begin{pmatrix} C_n \\ A_n \\ E_n \end{pmatrix} \quad (1)$$

In this context, the respective capability refers to the general technological or business domain (e.g. biochemistry). Its ability is the indicator for the application in this field (e.g. a synthesis procedure or filtering technique in the field of biochemistry). Finally, the expertise level gives information about the expertise of the firm in that particular field gained so far (Ahrweiler et al. 2004). To give a more detailed example we show in equation (2) an exemplary knowledge stock $\overline{K_J}$ of firm j:

$$\overline{K_J} = \begin{pmatrix} 1 \\ 4 \\ 2 \end{pmatrix}, \begin{pmatrix} \mathbf{47} \\ \mathbf{8} \\ \mathbf{9} \end{pmatrix}, \begin{pmatrix} 56 \\ 2 \\ 7 \end{pmatrix}, \begin{pmatrix} \mathbf{143} \\ \mathbf{9} \\ \mathbf{1} \end{pmatrix} \quad (2)$$

Furthermore, it is assumed that the knowledge owned by a firm will not be entirely used for the production of a certain good. There are knowledge pieces $IH_{i,j}$ in the knowledge base of a firm which are well known to the firm, but are at a particular moment in time unnecessary for production. Knowledge pieces which are used for the production of goods are part of a so called *innovation-hypothesis* (Gilbert et al. 2001, Ahrweiler et al. 2004).

$$\mathrm{IH_j} = \begin{pmatrix} 47 \\ 8 \\ 9 \end{pmatrix}, \begin{pmatrix} 143 \\ 9 \\ 1 \end{pmatrix} \quad (3)$$

Based on the information given in the innovation hypothesis the model computes the product category, its quality and its price. A particular feature of the SKIN model is its endogenous representation of demand. In addition to end consumer demand, each firm in the model demands input products in order to be able to produce and sell products which are also computed based on the firm's innovation hypothesis. These input products, in turn, are products which need to be produced by other firms. As a result, the model creates highly dynamic value-chains in which demand and supply are coevolving over time. However, despite the interesting dynamics created, products in the SKIN model are only characterised by their individual product category, their prize and the quality which leaves only limited possibilities to consider for example demand heterogeneity.

Another interesting approach, related to the model elaborated in the later chapters, is the model by Marco Valente which has been used in several papers (see for example Valente 1999, Valente 2009, Bleda, Valente 2009, Ciarli et al. 2010, Valente 2012). Products in the model by Valente are represented as vectors over a set of dimensions representing different product characteristics. In Table 1 the generic value v_X^i is the measure of product X in respect of characteristic i.

Table 1: Products' Quality Values (Source: own illustration based on (Valente 2009).

	Char. 1	Char. 2	…	Char. m
Prod. A	v_A^1	v_A^2	…	v_A^m
Prod. B	v_B^1	v_B^2	…	v_B^m
…	…	…	…	…
Prod. N	v_N^1	v_N^2	…	v_N^m

As a special feature, the model considers consumers to behave boundedly rationally with only limited information about product alternatives. Based on the work of experimental economist and the bias literature (Tversky, Kahneman 1981, Kahneman et al. 1974) consumers in the model are assumed to choose products as follows:

- At the beginning consider all options that may potentially be chosen.

- Choose one characteristic of the m characteristics available.
- If one single option scores highest in respect of that characteristic, take this product.
- Otherwise, if more than one option scores similarly in respect of the adopted characteristic, remove the options with values lower than the maximum, and restart from step 2.

For example, the paper (Valente 2012) analyses two main scenarios representing different assumptions about how consumers reach their purchasing decisions. Based on the different results from the two scenarios the author concludes that the demand side and especially the consumer's behaviour should be given as much relevance as the supply side in describing market properties. However, although the model incorporates a fascinating approach to consider the multidimensional characteristics of products, it oversimplifies the role of firms and their innovation because it does not consider the knowledge level of firms.

Another interesting approach which analyses the importance of heterogeneous consumers is the model by Zakaria Babutsidze (2015). In his paper he explains a simple model of boundedly rational firms in which the heterogeneity of a firm's market knowledge, R&D behaviour and firm size arises endogenously. One key element of this model is his unique representation of demand, which is also based on the work of Lancaster (1966). The model by Babutsidze considers that consumer preferences are located in a taste space, i.e. a uni-dimensional periodic lattice – Salop's circle.

His results show, depending on parameter constellations, three regimes in which optimal behaviour of a typical firm is qualitatively distinct: (i) no R&D, (ii) R&D only on familiar markets (no diversification) and (iii) R&D on unknown markets (diversification). The market in the model also shows interesting features of the equilibrium firm size distributions. The resulting firm size distributions are fat-tailed and positively skewed thereby reproducing interesting stylised facts (see also Gibrat 1931, Lucas Jr 1978, Pavitt et al. 1987).

Finally, the so called TEVECON model by Paolo Saviotti and Andreas Pyka is an agent-based model which directly consider demand-side effects and has been applied to different scientific issues (see for example Saviotti, Pyka 2004, 2012, 2013b, 2013a). The TEVECON model is based on the work of Saviotti (1996) and represents an endogenous growth model in a neo-Schumpeterian fashion. The key characteristic of the model is that the economic system is composed of a number of sectors which are created endogenously in the model. New sectors emerge due to the innovation dynamics created within the existing ones. An interesting model extension is presented in (2012, 2013b, 2013a) in which the focus of the models lies on the co-evolution of demand and supply and the qualitative change within industries. The model considers different preference systems of consumers and shows for example that a progressive preference system results in higher rates of growth of income and of employment than conservative preference systems and that growing wages and growing levels and intensity of human capital foster long run economic development.

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