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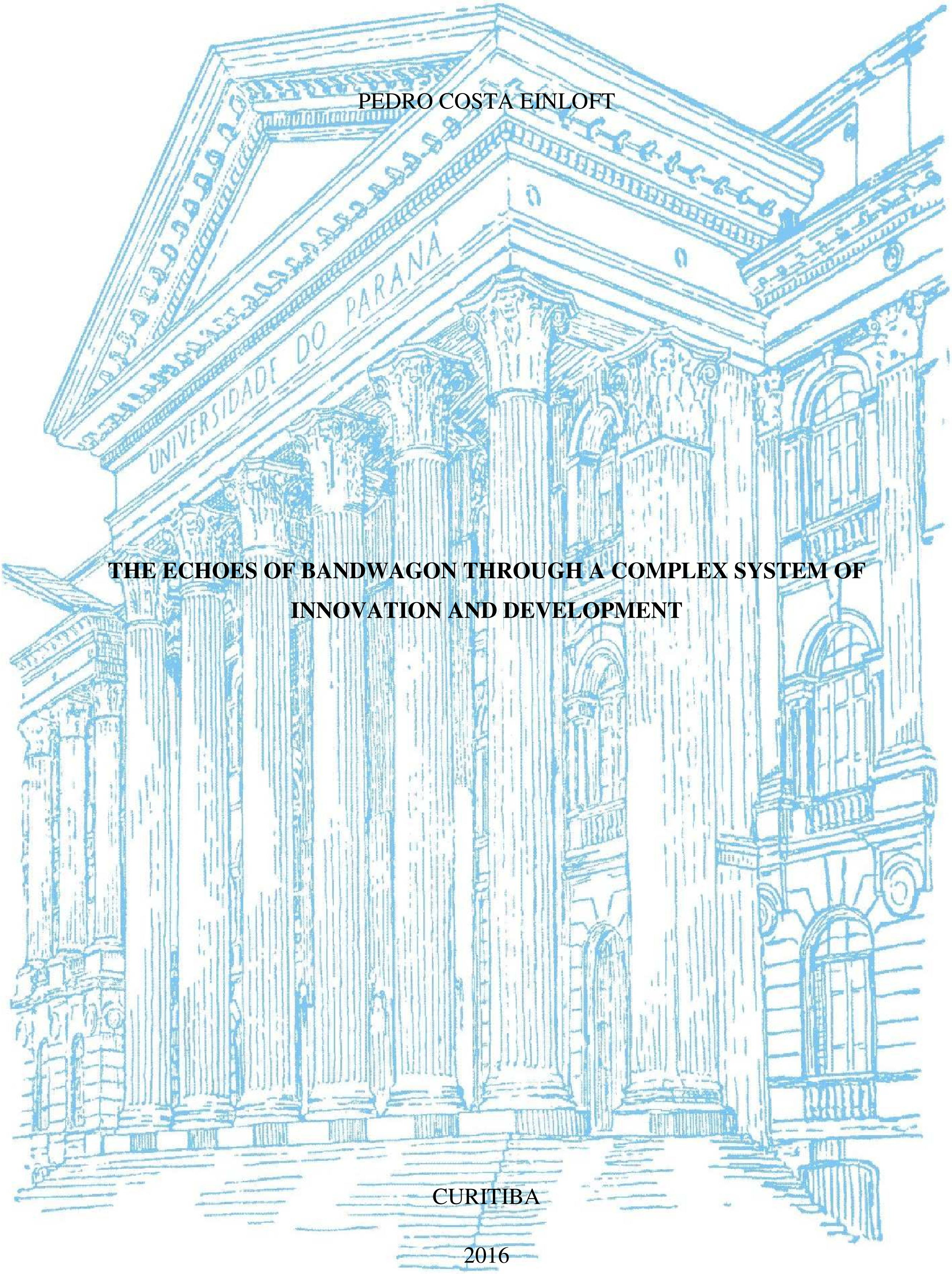

THE ECHOES OF BANDWAGON THROUGH A COMPLEX SYSTEM OF INNOVATION AND DEVELOPMENT

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PEDRO COSTA EINLOFT

THE ECHOES OF BANDWAGON THROUGH A COMPLEX SYSTEM OF INNOVATION AND DEVELOPMENT

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Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em DESENVOLVIMENTO ECONÔMICO da Universidade Federal do Paraná foram convocados para realizar a arguição da Tese de Doutorado de **PEDRO COSTA EINLOFT**, intitulada: "**The Echoes of Bandwagon Through a Complex System of Innovation and Development**", após terem inquirido o aluno e realizado a avaliação do trabalho, são de parecer pela sua APROVAÇÃO.

Curitiba, 28 de Abril de 2016.

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"O importante é vencer, tudo e sempre"'
(Ayrton Senna)

"I think the next century (21st) will be the century of complexity"'
(Stephen Hawking)

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RESUMO

Esta tese busca analisar como a heterogeneidade de demanda, aqui representada por comportamento bandwagon e desigualdade de riqueza, molda o processo de decisão da firma sobre qual tipo de inovação visar, dados os padrões de mercado emergentes dessas características microeconômicas em um mundo no qual os consumidores são heterogêneos e interagem entre si. Dois Modelos Baseados em Agentes são desenvolvidos com o objetivo de analisar esse assunto que, além de complexo, ainda está para ser analisado na literatura econômica: enquanto existem diversos estudos sobre difusão de inovação, nenhum até o momento se aprofunda nos mecanismos micro-mezzo-macro através dos quais a interação entre os agentes afetam a estrutura do mercado, o que faz com que as firmas mudem suas estratégias de inovação, gerando diferentes resultados macroeconômicos. Uma nova estrutura para interação entre agentes é introduzida na qual os consumidores não são apenas nódulos estáticos com redes sociais pré-estabelecidas - como nos ambientes *small world* - mas caminham livremente através do plano da economia estocasticamente gerando, a cada ponto no tempo, novos processos de interação com outros agentes, desde que os mesmos estejam no *awareness radius* dos consumidores, uma medida criada com o objetivo de controlar a racionalidade e a capacidade de percepção dos agentes. A heterogeneidade no primeiro modelo advém das preferências do consumidor com relação à adoção de novas tecnologias, das quais *thresholds* estocásticos são derivados, enquanto que no segundo modelo os consumidores possuem diferentes dotações de riqueza, o que faz com que os mesmos se comportem de maneira diferente quando avaliam a compra de um novo produto de alta tecnologia e preço. Os resultados do primeiro modelo mostram que um aumento na capacidade de percepção dos consumidores e em suas propensões a serem influenciados por outros consumidores detentores de produtos de melhor qualidade aceleram a saturação ao longo do ciclo de vida do produto, levando as firmas a preferir inovações de produto a inovações de processo, o que gera maiores custos, mark-ups e lucratividade. Apesar da existência teórica de que exista uma ambiguidade nos efeitos da desigualdade sobre inovações, o segundo modelo sugere que uma sociedade mais igualitária eleva ambos os tipos de inovação, além de levar o mercado a ser mais competitivo e apresentar menores preços, mark-ups e margens de lucro.

Palavras-chave: Inovação. Comportamento Bandwagon. Saturação de Demanda. Ciclo de Vida do Produto. Complexidade.

ABSTRACT

This dissertation seeks to address the issue of how demand heterogeneity, represented here by bandwagon behaviour and wealth inequality, shapes firm decision on the type of innovation to pursue, given the emergent market patterns from microeconomic traits of a world with heterogeneous interacting consumers. Two agent-based models are develop in order to tackle such complex subject yet to be explored in the literature: while there are several studies on innovation diffusion, none so far have explicitly analysed the micro-mezzo-macro mechanisms through which consumer interaction and heterogeneity alter market structure, thus changing firms decision on innovation which generates different macroeconomic outcomes. A new framework for agent interaction is introduced in which consumers are not static nodes with pre-set social networks, such as in small worlds environments, but freely walk through an economic plain stochastically creating new interaction processes at each point in time with other agents inside their awareness radius, a measure created to control rationality and perception. Heterogeneity in the first model comes from consumer preferences toward new technologies from which stochastic threshold values are derived, while in the second consumers have different wealth endowments, which makes them behave differently when considering the purchase of a new costly high-tech product. Results from the first model show that increasing consumer awareness and making them more adept to be influenced by the new technologies other consumers own speeds up saturation over the product life cycle, leading firms to prefer product other than process innovation, which yields higher costs, mark-up and profitability. Despite the existence of an ambiguous theoretical effect of inequality over innovation, second model results suggests that a more egalitarian society drives both product and process innovations up and leads to a more competitive market, with lower prices mark-ups and profit margins.

Keywords: Innovation. Bandwagon Behaviour. Demand Saturation. Product Life Cycle. Complexity.

Capítulo 1

Introduction

Which came first? Demand or supply? Consumption or production? These questions are probably more well-known to an economist than the famous egg versus chicken conundrum. And probably just as hard to answer, or at least to formulate a theory on the subject that would satisfy economic Greeks and Trojans, keynesians and hayekians. One can argue that there can be no consumption without a given good to be consumed and that is certainly correct, but it's also quite simple to perceive that this given good does not necessarily need to have been produced by men, or firm.

Let us date back to the stone age, when our ancestors were struggling to find better ways to defend themselves, to better manipulate objects, to storage food and basically to survive. There were no firms back then and even so there was consumption; of fruits, wild animals, water. But with evolution came the needs to new goods. The kind that could not be found ready in nature, like a sharp stone at the end of a wooden stick, one of the first goods ever produced and, who knows, maybe even traded for some berries. In fact, Malthus argues that "'the savage would slumber forever under his tree, unless he were roused from his torpor by the cravings of hunger or the tremblings of cold"[1]

It is hard to picture a cave man manufacturing something useless and trying to convince himself or his fellow cave men otherwise. Nevertheless, moving a little further in time, one can argue that when Colombo discovered America, Indian people had absolutely no need of a mirror and yet they were willing to trade valuable resources for it.

Say (2001) state in his famous Say's Law that the supply always creates its own demand, which doesn't seem to hold. About only one percent of the patents registered in the United States end up as a successful product[2]. But Ricardo (1817) has a point when he states "give men but the means of purchase and their wants are insatiable". One quick look in any online shopping website and one can find products such as a shirt with a built-in wi-fi signal detector and a toilet paper that glows in the dark. And be aware: these are examples of successful patents.

Despite the value or usefulness of a given invention, in the end it cannot escape Marshall's Law of Diminishing Marginal Utility[3]. A person can have an unlimited

[1] Malthus (1798).

[2] According to the United States Patent and Trademark Office.

[3] Marshall (1890).

number of wants, but the amount of each want is satiable so there is saturation at the individual's level. In other terms, the first slice of pizza is always better and an individual probably does not need two refrigerators for example.

Resemblant to Marshall's theory is the Engels Law. More than 150 years a go, Engel (1857) perceived that the share of food consumption in a consumers basket is decreasing in income. Several subsequent studies, like Houthakker (1987) obtained not only the same conclusion but also that most type of products are bound to the same law. If this is true, Engels law can be viewed of a general law of consumer behaviour: they constantly change their basket of consumed goods according to their income. This could be viewed as a Law of Diminishing Marginal Utility from the demand side.

The microeconomics of demand is much more complex and involves a subject that only recently has been brought back to the economic theory spotlight: the heterogeneity of consumers and their behaviour, as an alternative to the utility maximizer rational representative consumer of neoclassical Consumer Theory. It is important to acknowledge, however, that the study of consumer behaviour need not to be seen as a two-sided quarrel between economists who comes from neoclassical and heterodox currents of thought. In other words, there is no need to separate the great work of Nobel laureates Daniel Kahneman and Gary Becker into completely different universes.

It is not the concept of utility or rationality that hinders depth of analysis in individual decision, but the limitations of the framework in which it is presented and developed, where the all seeing economic man reigns sovereign able to perceive everything in the world around him and to predict future with ease. As Simon (1955) stated, what traditional theory was in need was "a kind of rational behaviour compatible with the access of information and computational capacities actually possessed by organisms, including men"'[4]

Take for example a high school student. He might decide to start using drugs because most of his friends - or the group he is interested to be a part of - is doing it; and his decision can arise both from a desperately irrational need to fit in or a thoughtful process of pros and cons. In the second case, however, to assume that the student had all the pay-offs associated with possible choices available to him during decision process is arguably unrealistic. It is a methodological problem between a descriptive and a normative formulation.

This brings us two important topics that somewhat limit the possibility of an individual to behave like a neoclassical economic man: bandwagon behaviour and awareness, both playing a key role in this thesis. Bandwagon is the willingness of an individual to buy a product based on how many others have purchased it, while awareness is the personal bounded rationality each individual has, related to the extent of his social networks and general understanding of the world around him. These are difficult aspects of human behaviour to be formalized in a model for example. Complexity is the key word here and has long been used by economic authors to justify the negligence

[4]It is important to stress here that the concept of bounded rationality used further ahead on this thesis do not mimic those of the life work of specific scholars such as Simon or Sargent, but a more general one that opposes to global, perfect or neoclassical rationality. See Barros (2010), Sent (1997) and Sargent (1994) excellent reviews on different concepts of rationality used in the work of several researchers.

towards these subjects. In fact, as brilliantly cited by Leibenstein (1950):

> "One reason why the interpersonal effects on demand have been ignored in current texts may be the fact that Marshall did not consider the matter in his Principles[5]. We know, however, from Marshall's correspondence[6], that he was aware of the problem. Both Cunynghame and Pigou pointed out that Marshall's treatment of consumers surplus did not take into account interpersonal effects on utility. Marshall seemed to feel that this would make the diagrammatical treatment too complex."

Leibenstein draws from the work of past economists, psychologists and sociologists - such as Veblen, Rae and Morgenstern - on fashion and conspicuous consumption to formalize the concept of bandwagon behaviour, but even himself surrenders to the task of taking all of its nuances and complexity in consideration, deliberately abstracting from sociological and psychological elements to focus solely on the effects of conspicuous consumption on demand functions.

Another subject in need of better micro-foundations is income and wealth inequality. Driven by the recent increase in American and global income inequality, economists have renewed their interest in the subject. However, no consensus is found amongst the several causes proposed to explain the phenomenon and even less about its macroeconomic impacts[7].

While this lack of consensus might exist due to the simple fact that inequality may have no impact on the macroeconomic variables of common interest such as growth, employment, poverty, technological change, political outcomes and financial crisis, it might also be the case that economists have not fully understood exactly how inequality relates to these other subjects. Mechanisms of transmission from inequality to macroeconomic variables are still mostly unknown to economic theory due to the lack of understanding on how different individuals behave according to their social status position in the relevant population. This is possibly another problem of microeconomic foundations shortage while trying to tackle an economic problem.

It is safe to assume that researchers in economics have a much higher computational capability nowadays than they had in the middle of the past century, specially due to the use of computer simulations. These capabilities, however, have until recently been used by mainstream economics to answer the wrong questions. Instead of following the lead of other sciences an diving into the world of complexity, it was mostly used to generalize the same old neoclassical paradigms with no contribution to the better understanding and development of microeconomics. Economic theory remained stuck in an equilibrium state too reductionist to understand the complexity of our modern society.

However, as economic theory was gifted with the work of John Maynard Keynes as a silver lining of the 1929 great depression, agent-based models started to arise as an important and modern alternative after 1987 and 2008 financial crisis and were used not

[5] Marshall (1890).

[6] Pigou (1903).

[7] See Moss et al. (2013).

only to model the interaction between shareholders but to study how all agents in the economy behave before and during a financial crisis.

Nowadays ABM's have been growing in popularity and have yielded strong contributions also in the field of innovations[8], considered to be one of the main forces driving economic growth and development. The fact that Robert Sollow TFP[9] black box might not be so black any more has certainly something to do with understanding how the engine of innovation is greased. One thing that is safe to assume is that innovation is viewed not only as a simple research & development decision, but a complex process of integration between supply and demand factors.

It is exactly this complex integration that we seek to better explore in this thesis by studying how demand heterogeneity in the form of bandwagon behaviour and wealth inequality shape the market and, consequently, firms decision about process and product innovation, which upon aggregation, can finally yield us the complete path from micro through mezzo to macroeconomics. An agent-based model framework seem to be the right choice for the task.

To connect the links between these three economic levels we draw important insights from Product Life Cycle Theory, first presented by Kotler (2005). Besides being a marketing theory largely utilized by most firms to assess and predict diffusion times and patterns, it is the only economic life cycle theory to incorporate demand aspects on innovation diffusion and firm innovative decisions.

This thesis is organized as follows: chapter 2 brings a brief literature review and a discussion about strategies to model bandwagon behaviour and wealth inequality into an agent-based environment. Chapter 3 and 4 contains the two agent-based models in which the goal is to assess how firms shape product and process innovation decisions based on bandwagon behaviour, in the first model, and wealth inequality in the second. Finally, chapter 5 brings general conclusions.

[8]See Dawid (2005) for a survey on Agent-based models of innovation.

[9]Total Factor Productivity.

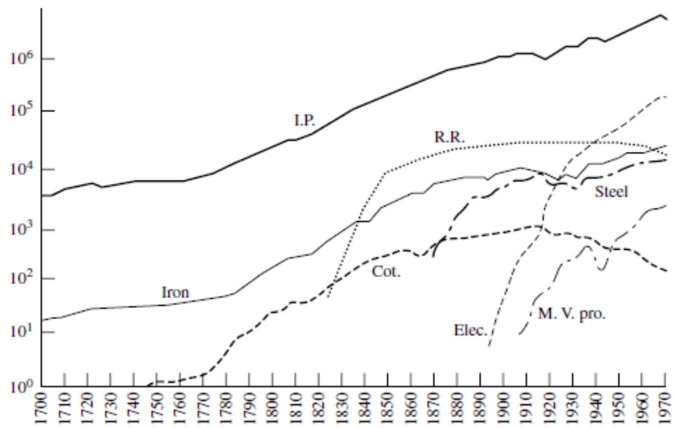
Capítulo 2

Literature Review and Some New Insights on Innovation Diffusion

2.1 Life Cycle Theory

A Life Cycle is not by any margin an exclusive economic phenomena. From natural to social sciences, from bacteria to sales the majority of growth processes follow the same pattern of birth, acceleration, dis-acceleration and decline, generating a S-shaped curve. It is no different in economic regimes. Using the words of Aoki and Yoshikawa (2002),"plot a time series of production of any representative product such as steel and auto-mobiles, or production in any industry, against year, and, with few exceptions, one obtains an S-shaped curve"(see figure 2.1 below).

Figura 2.1: Demographic Transition and the Impact on Growth: the case of Japan



Notes: Industrial production (I.P.); railroad mileage (R.R.); raw cotton consumption (Cot.); production of iron (Iron); steel (Steel); electricity (Elec.); and motor vehicles (M.V. Pro.).

Source: Rostow (1978).

It is not difficult to understand the mechanism behind a S-shaped curve. In fact the key words here are also one that motivates economic science: scarcity and saturation. In the beginning there are almost no constraints for growth, be it space, food, knowledge, demand: they are usually abundant at first so the process can grow exponentially with no boundaries. But when it reaches a certain stage scarcity begins to take its toll and the agents involved start to feel the lack of resources, preventing them from freely "reproduce". The growth then begins to slow down until it reaches a maximum possible equilibrium (achieves full saturation) or to decline, if it cannot maintain itself at a given level for internal or external reasons. For example, a given product can never surpass a certain level of sales even if its price tends to 0, because there is a maximum amount of people in the market. Sales will never grow to infinity.

2.1.1 Locational Life Cycle

There are three life cycle theories in Economics in the present day focusing on slightly different aspects of the theory: industry location, technology and sales/marketing.

The first one was introduced by Vernon (1966) as a criticism and alternative to the theory of comparative advantage. He argues that it is not the cost of resources that defines the arrival of new sectors and product innovations, but the proximity to knowledge sources i.e. the ability to understand the needs of the market, from both firms and consumers. Two good examples are the advent of the home washing machine as a need to reduce the costs associated with laundresses; and the tractor, a incredibly effective labour and time saver for the industry.

It is important to note though that needs arising from firms are more easily identifiable than the ones of consumers. Firms usually know what they need to improve their production system, but it is not always the same with consumers and their needs. That is why the income of a country and the size of its markets are very important factors regarding product innovation. The higher the income and the variety of latent needs the higher is the probability of success in the introduction of new goods. Consumers must have the means and the wants to pay for modern and expensive products. That would be why, according to Vernon, the United States would be the perfect place for the birth innovative activities and also why his life cycle hypothesis is called the locational life cycle.

However, it is not only in this first birth stage (called new product by Vernon) that demand and market structure plays an important role on innovation. Although Vernon did not developed the process of decision on the types of innovation through his life cycle, he did left us with impressive insights about it. He states that an adequate answer to the question of how long a product takes to reach its stages "must surely be a complex one". This is mainly because investment decisions are not taken in a rational way and so threats have in general more impact over firms decision than simply opportunities. Firms feel most threatened by competition and will usually do whatever it takes to secure markets, home or abroad, so they fear loosing the international market once internal demand saturates[1].

Apart from these considerations, the two other Vernon stages, maturing product and standardized product, are mainly guided by costs of production and the focus of

[1] See Schmookler (1966).

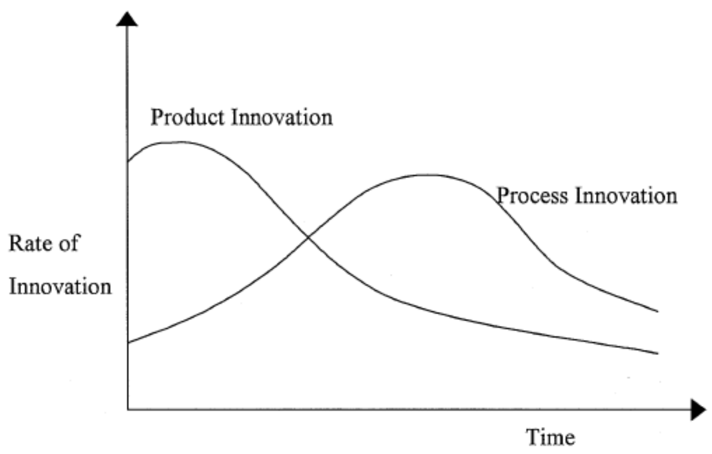
his research is indeed finding the pattern of industry location. In the maturity stage the industry is usually located at other developed countries and, when the product reaches full standardization and presents reduced costs the industry tend to move to developing/underdeveloped countries to grab the last bit of world demand and to reduce production costs even more.

2.1.2 Technology Life Cycle

Utherback and Abernathy (1978) follow the work of Vernon but focus on explaining the life cycle through the dynamics of product and process innovation. They divide what they call technology life cycle into two main stages based on the arrival of the dominant design. The first stage, pre dominant design, is subdivided into two periods: embryonic and prenatal, but they are, in fact, very similar to the new product stage of Vernon because understanding and being able to adapt to the needs of the consumers before the dominant design arrival is key.

In the second stage that takes place after the arrival of a dominant design, however, demand effects seems to be completely ignored by the authors and the decision between process and product innovation arises from diminishing technological opportunities and from what seems to be an imposed pattern of ordering. First, firms invest only on product innovation in order to further develop the already defined *de facto* standard. It is not viable to invest in process innovation because sales are too scarce for cost reducing to have an impact. As demand grows process innovation becomes more and more profitable and diminishing returns to technology kicks in (see the figure 2.2 below). As pointed by Adner and Levinthal (2001), diminishing returns to technology is heavily refuted in the literature, as well as the hypothesis that firms do not engage on cost reducing efforts during earlier stages of the life cycle.

Figura 2.2: Dynamics of Innovation on Technology Life Cycle



From Utterback and Abernathy (1975)

Still according to the technology life cycle product innovation should decrease after the earlier stages and eventually come to a full stop, what is also not confirmed in the literature (Klepper (1996)). In addition to these critiques, technology life cycle pays little attention to technology diffusion, mainly guided by the interaction of agents in the form of social interactions[2]

2.1.3 Product Life Cycle

Finally, we have the Product Life Cycle, brought to attention by Kotler (2005). Despite being considered a marketing theory, it brings important insights about how the diffusion of technology takes place through a consumer interaction perspective. Since it is the only life cycle theory that disaggregates industry behaviour into single products and series of products sales evolution, it is key for those like us who wish to study the microeconomic drivers of innovation from consumer networks. Take the smartphone industry for instance. To be able to understand how the whole industry develops we need to examine the precesses behind each one of the individual products released. In the case of product life cycle, an Ipad 6 for example would be a single product while the family Iphone 6, Iphone 6s and Iphone 6c would be the series of products. The aggregation of life cycle of these products will then yield a pattern for Apple market evolution. In other words, it is possible to observe the life cycle of each product resulted from an incremental innovation in a given industry, and not only the big picture.

Figura 2.3: Product Life Cycle

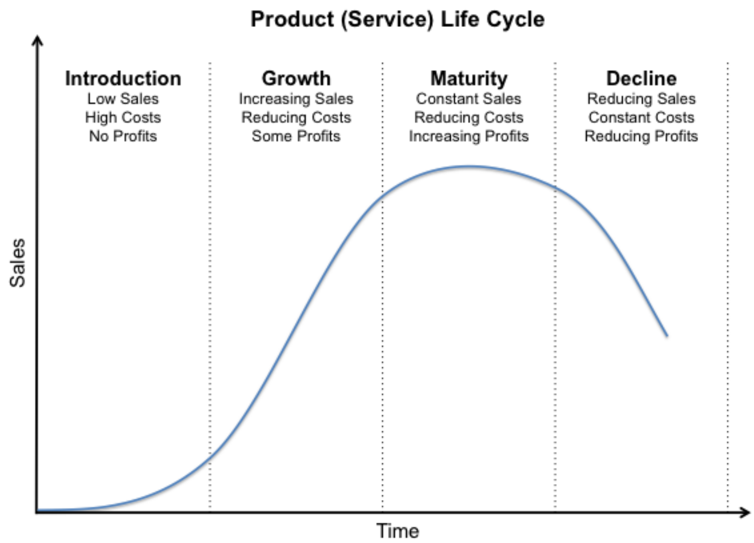


Figure 2.3 above shows the four stages of product life cycle. In the first or introduction stage, sales grows really slow because the majority of the population is still unaware of the product and for that are not, the price is still prohibitive. Companies spend a lot of money on marketing during this stage and profits tend to be very low or even negative. Since very few people own the product, the potential for diffusion through consumer interaction i.e. word of mouth is little but already begins to take place.

[2] See Granoveter (1978), Young (2002) and Acemoglu et al. (2011).

When marketing has done its job and new product and process innovations have been applied to the product fast diffusion starts to happen and due to a large potential demand sales increase exponentially due to fast information dissemination of information and profits usually rises.

In the third stage, maturity, a lot of consumers already own the product and in consequence the space for growth starts to get narrow. Growth starts to dis-accelerate as market reaches its saturation point but profit tends to reach its maximum even if market is highly concentrated since a lot of product and process innovation took place along with the rise of economies of scale . If an industry or a product reaches its declining and final stage it means that another new substitute product or technology is stealing demand.

In the case of high-tech durable goods the only option a firm reaching maturity has is to heavily engage on R&D trying to sustain a constant de-maturity process[3] in which bandwagon behaviour plays a key role. Unless there is a ground-breaking innovation almost similar to an invention de-maturity processes usually occur at the level of the product and not the industry. Some examples include the Iphone generations, the TVs screen resolution increase and the processing capacity of computers. These de-maturity process have the power to basically bring saturation down to the first stage levels, since nobody will own the product and most likely the majority of consumers will be interested in purchasing it at some point in time.

2.2 Bandwagon Behaviour, Wealth Inequality and the Diffusion of Innovations

2.2.1 Bandwagon Behaviour and Innovation Diffusion

Theories about interpersonal effects on individuals behaviour and consumption patterns in the form of discussions about fashion, fads and conspicuous consumption dates back at least to the Roman poet Horace. Several subsequent psychologists, sociologists and also economists, like Veblen, Rae e Von Morgerstern have developed insights about how the behaviour of our fellow human beings helps to shape our own. Although even Marshall have acknowledged that the subject was important in the formulation of an economic theory of wants and needs, he decided to overlook it in his Principles due to the complexity require in the formalization of these ideas. And so, economy left the matter outside the scope of classical theory and several years would be required to bring it back to the spotlight.

It was not until Leibenstein (1950) work that an attempt was made to incorporate interpersonal effects in classical utility and demand functions. But even then the concept developed was too minimalist and imprisoned by the requirements of perfect information of agents and the need to find an equilibrium solution. In fact, the only assumption relaxed was additivity, with the addition of a therm on utility function that captures the individual valuation for the amount of a certain good the rest of the popu-

[3]See Higuchi and Trout (2008).

lation consumes. According to Leibenstein, this valuation follows a diminishing returns behaviour which he calls diminishing marginal external consumption effect.

From this point on, authors like Simon, Schelling, Turner, Tversky, Kahneman and many others started to effectively create stronger connections between economics, psychology and sociology, questioning the realism behind the assumptions of classical economic man and creating a new line of research which now is best known as Behavioural Economics. But BE[4] is not only about de-constructing the "super-powers"' of classical agents, but to better understand the real complex mechanisms behind our every day decisions, something that is undoubtedly necessary. But maybe the most important tools BE brings to economist is the possibility to consider the right causality direction between macro and microeconomics.

Granoveter (1978), on his seminal paper about collective behaviour implies just that when he say:

> "But I will argue here that knowing the norms, preferences, motives and beliefs of participants in collective behaviour can, in most cases, only provide a necessary but not a sufficient condition for the explanation of outcomes; in addition, one needs a model of how these individual preferences interact and aggregates."'

And he continues:

> "Because theories oriented to norms lack such a model, they end up assuming a simple relation between collective results and individual motives: that if most members of a group make the same behavioural decision we can infer from this that most ended up sharing the same norm or belief about the situation, whether or not they did so in the beginning."'

Granoveter (1978) and Granoveter (1986) introduces dynamic characteristics in a model of collective behaviour and interpersonal effects, unwillingly[5] modifying Leibenstein's model in three important ways: first he shifts interpersonal effect on the utility function from total consumption of agents to how many agents are consuming the product at a given time, which seems more realistic. Second, he breaks perfect information paradigm and set that agents have an adaptive behaviour, being able to acknowledge only past quantities of adopters. And third, he makes demand heterogeneous by setting a different interpersonal effect for each consumer, given by a probability distribution, in the form of minimum threshold values of adoptions by other consumers that would trigger each individual to follow the bandwagon and follow the collective behaviour. His model became known as the Linear Threshold Model, largely used in innovation diffusion literature.

As also pointed out by Rosenkopf and Abrahamson (1997) and Rosenkopf and Abrahamson (1999), collective behaviour, social networks and interpersonal effects are

[4] Behavioural Economics.

[5] Granovetter does not seem to draw from the work of Leibenstein but the resulting models are theoretically related.

closely related to the intrinsic process behind innovation diffusion and these process are not limited only to consumer interaction, they also apply to the firms decision to adopt a certain technological innovation in their production processes.

It is important to note, however, that the use of thresholds to characterize individuals preferences towards the adoption of new products, technology or behaviour can lead to counter-intuitive results in which very small shifts in the initial distribution of thresholds (preferences) might have extremely strong effects on the extent of a product diffusion. Bandwagon theories of innovation can be broadly classified in two types: Efficient-Choice theories and Fad theories

Efficient-Choice theories assume that agents adopt innovations based on information about their efficiency, utility of profitability[6] varying only regarding the availability of this information. When information is complete[7] firms instantly receive information about the profitability of a new innovation and decide to adopt solely based on their internal capacities and technology. Imperfect information[8] may arise from simply uncertainty about profitability of innovations or because of defined social networks with closed access to external agents. In both cases, available information grows with the evolution of the number of adopters.

Fad theories of bandwagon focus on the fear of incurring serious costs from missing the opportunity to adopt a successful innovation. It can be an institutional cost[9], in which firms by not adopting a successful innovation have their image jeopardized with stakeholders, consumers and society in general, or a competitive cost[10] in which a firm fails to implement a key process innovation that greatly reduces cost and loses competitiveness in the market. Fad theories are also usually associated with reputation issues where adoptions by agents with a high reputation influences imitations by lower-reputation ones seeking to remain competitive and strong before stakeholders and consumers.

As mentioned before, linear threshold models of bandwagon can lead to unrealistic results specially because every time the minimum threshold among non-adopters is higher than the number of adopters diffusion stops. The problem is deepened by the fact that little is known about the real distribution of thresholds among consumers for each type of product or behaviour being diffused. It is also arguable to assume that these given thresholds are fixed or even exists since consumer preferences are often changing, human memory is imperfect and a lot of decisions are taken based on cognitive biases and heuristics[11].

One alternative is to consider stochastic threshold processes instead of deterministic. In this case, probability of adoption increases with the number and percentage of individuals that already adopted a given innovation. In this case, a given innovation might fail to diffuse completely not because a certain threshold was reached, but because

[6]Efficient-Choice theories are usually utilized to characterize firms decision process, but can be easily modified to represent consumer choices by e.g. using the concept of utility other than profitability

[7]See Fudenberg and Tirole (1983), Katz and Shapiro (1985).

[8]See Valente (1996) and Rosenkopf and Abrahamson (1997).

[9]See Rosenkopf and Abrahamson (1993).

[10]See Rosenkopf and Abrahamson (1993) and Banerjee (2014b).

[11]See Gilovich et al. (2008) for more information on cognitive biases and heuristics.

demand did not grow fast enough for the innovating firm to continue accruing profits from the new product or technology.

Young (2002) and Acemoglu et al. (2011) offer alternatives[12] or extensions to the linear threshold model in order to address these issues. Drawing from the ideas of Blume (1993) and Ellison (1993), Young develops a stochastic threshold model in which the probability of a given person to adopt one of two possible actions in a given time period is assumed to be a increasing logistic function of the number of his or her neighbours who have already adopted it. Acemoglu also develops a stochastic threshold model in which consumer decision to adopt a given innovation follows a Bernoulli trial with an homogeneous parameter among consumers.

Product Life Cycle Theory can be called to help clarifying the pattern of stochastic thresholds in a population. There are several authors[13] that contributes to diffusion literature by performing a categorization of adopters based on their innovativeness profile i.e. the point in time they decide to adopt the new product or technology. A recent empirical study performed by Moore (2005) finds percentages for each one of the consumer profiles in the market. The following profiles are similar to Rogers and are presented in decreasing order of appreciation towards new technology or products: visionaries (12.5%) may not buy the product at the time of the release but they have a high probability to buy it soon. Pragmatists (35%) and conservatives (35%) correspond to the bulk of population and are similar to early majority and late majority profiles. Finnaly, skeptics (15%) rarely care for new products even when the majority of the population owns it.

2.2.2 Inequality and Innovation Diffusion

Contrary to the effects of bandwagon behaviour, the relationship between inequality and innovation diffusion has received little attention in economic research[14]. Despite the fact that inequality is a hot topic in economics at the moment due to the alarming empirical confirmation[15] that inequality has been significantly increasing in the past 30 years in America and the world, there seem to be almost no interest so far in the microeconomic issues of inequality, which could help clear most the mechanisms through which inequality influences - or not - macroeconomic variables.

According to Moss et al. (2013), this could be due to the lack of behavioural studies regarding the heterogeneity of consumer decision under different wealth and social status. Although few, there are some important conclusions about behaviour under different levels of inequality.

Loughnan and et. al. (2011) suggests that societies with greater income inequality tend to exhibit higher self-enhancement and optimistic behaviour from individuals with a notably better social status than the average. Consequently, these individuals tend to be more adept to risky investments.

[12] Stochastic threshold models are not new in social sciences. See Dieckmann and Mitter (1984) for early usage examples of these types of models.

[13] See Rogers (1995) and Moore (2005) for good examples.

[14] See van den Bulte and Stremersch (2013) and Kandler and Steele (2009) for important exceptions.

[15] See Piketty (2013).

Franck et al. (2010) argues that the recent increase in inequality stimulated a cascade effect on consumption with individuals from middle and poor classes trying to imitate the consumption patterns of other individuals in their social networks which earns marginally more by contracting debts. This positional consumption behaviour[16] is one of the arguments that could explain Piketty's claim that inequality was one of the main causes for 2008 financial crisis.

Theoretical formal models developed by Foellmi (2005), Zweimuller (2000) and Foellmi et al. (2014) suggest that inequality affects the firm decision between process and product innovation. Firms tend to consider the pay-off between producing only for the rich, with higher quality, which implies a constant effort on product innovation, and investing on process innovation to reduce costs and prices to reach a higher share of the market. They find that when firms seek to maximize profits higher inequality yields more product innovations from the market, leading to exclusion of a good part of the poorer consumers.

2.3 Modelling Bandwagon Behaviour in Agent-Based Models of Technology Diffusion

In this section we review some of the main strategies for modelling bandwagon behaviour and technology diffusion in agent-based-models.

2.3.1 Small World Networks and Threshold Models of Bandwagon

When modelling innovation diffusion through bandwagon behaviour economists and sociologists usually make use of directed and undirected graphs and small world networks as framework for the analysis. A directed graph is a set of vertices (nodes) connected by directed edges (links). The direction of the edges imply causality or direction of transmission. In an undirected graph the edges does not have directions implying that the interaction between nodes are symmetrical and transmission occurs from both sides.

Small world networks are graphs, usually undirected ones, arranged in a circle in a matter that each node connects to its closest k neighbours clockwise and anti-clockwise. Aside from the edges created this way, a few other edges are created randomly between the nodes. Small world networks were first discussed by psychologist Stanley Milgram[17]. the idea behind it is that despite the fact that most nodes (individuals) does not know each other (are connected to), they are a few steps[18] away from basically everyone else in the world. Milgram suggested that most of United States population is within six degrees of separation from one another.

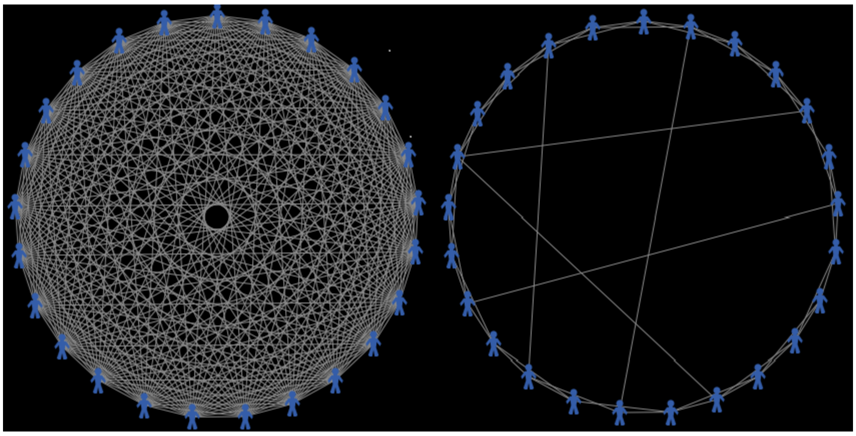
Small worlds also features a stochastic "rewiring"' rate, which is a constant probability that a certain node breaks one of his edges and creates another with a random

[16] Bernardino (2013) explores the issue of positional consumption in an agent-based model.
[17] See Milgram (1967).
[18] Maximum amount of edges he has to go through to reach the furthest agent in the graph

other end. This type of graph is very popular for being a elegant framework to capture individual bounded information[19] besides allowing control of important variables such as the length between nodes (number of steps required to reach one another) and clustering coefficient. It can also support both linear and stochastic threshold models of bandwagon. The model can also be extended to support reputation heterogeneity amongst individuals (nodes) in the stochastic case.

Figure 2.4 below show an example of two graphs with small world characteristics[20], the left one implying perfect information and the right one bounded information.

Figura 2.4: Perfect and Bounded Rationality Small World Undirected Graphs (Ring Shaped)



Consider a small world network represented by the undirected graph Γ, with a set of consumers (nodes) $\Omega = \{1, ..., N\}$ connected by a set ϵ of edges (links). Note that the bars delimiting the terms in the numerator and denominator of the first term of the equation denotes cardinality i.e. the number of agents on each of the sets In a linear threshold model, agent i will adopt an innovation at time k if:

$$\frac{|\{\bigcup_{t=0}^{k-1} \Phi(t)\} \cap \Theta_i|}{|\Theta_i|} \geq \phi \Rightarrow i \in \Phi(k) \tag{2.1}$$

where $\Phi(t, k)$ is the set of all agents who already adopted the innovation at time (t, k), $\Theta_i = \{j|(j, i) \in \epsilon\}$ is the set of neighbours of agent i connected by the set of edges ϵ, and ϕ_i is the deterministic threshold of agent i.

Note that, as ϕ_i is deterministic, if the percentage of neighbours who already adopted the innovation, given by the firs term of equation X, is less than ϕ_i, agent i will not adopt.

Acemoglu et al. (2011) develops a model, which he calls Stochastic Threshold Model, where thresholds ϕ remain deterministic, but consumers, after having there thresholds surpassed, immediately incur in a decision process to decide whether it adopts the

[19] A perfect information environment would be nothing more than the smallest world possible, with everyone directly knowing (being connected) everyone else.

[20] Be aware that Small World Networks does not necessarily need to be built in a circle or ring fashion.

product or not, following an irreversible[21] Bernoulli Trial with probability ρ to adopt $(x_i = 1)$ and $1-\rho$ otherwise $(x_i = -1)$. Agent i in this cases will consider the adoption if:

$$\frac{|\{\hat{\Phi}(0) \bigcup_{t=0}^{k-1} \Psi(t)\} \cap \Theta_i|}{|\Theta_i|} \geq \phi \Rightarrow i \in \hat{\Phi}(k) \tag{2.2}$$

where $\hat{\Phi}(t,k)$ is the set of agents considering adoption at time (t,k) and $\Psi(t) = \{i \in \Phi(t), x_i(t) = 1\}$ is the set of agents who effectively adopted at time (t).

Clearly, thresholds themselves are not stochastic, but the one time decision process through Bernoulli trial indeed is. The problem is that Acemoglu's model implies that consumers absolutely never consider, not even by a faint chance, to adopt a new product before reaching his threshold, even when he is already exposed to it by being directly linked with one or more neighbours who already adopted. This seems quite counter-intuitive and conflictual with some behavioural biases that creates randomness on consumer decision such as memory biases[22], humor effects[23], and impulsive buying[24].

Young (2002) develops a different approach that generates stochastic thresholds *de facto*. Agents are also distributed in a small world network and at each time t choose between consuming products A or B depending on their individual preferences but also on social pressure. The pay-off of agent i is given by an utility function of the form:

$$U_i = \sum \beta_{i,j} u(x_i, xj) + v_i(x_i) | \{i, j \in \epsilon\} \tag{2.3}$$

where $\beta_{i,j}$ is a weight for the social pressure given by the utility of conforming $(u(x_i, x_j))$ - with x_i and x_j being the state of choices[25] of agents i, j - and $v_i(x_i)$ represents the individual preferences of agents.

Agents update their state at each point in time according to a logistic function of the payoff difference between the two possible actions (consuming A or B). The probability of agent i to choose product A is thus given by:

$$\rho_i^A | x_{-i} = \frac{e^{\alpha[U_i(A,x_{-i}) - U_i(B,x_{-i})]}}{[1 + e^{\alpha[U_i(A,x_{-i}) - U_i(B,x_{-i})]}]} \tag{2.4}$$

where $x{-}i$ is the set of choices of all other agents such as $(i, -i) \in \epsilon$ and α is a parameter controlling the impact of the gap between states on the probability of adoption.

Young's stochastic model seems adequate to be considered closest to reality than Acemoglu's model or any other linear threshold model. However, a static small world network, while suitable to analyse process of diffusion, incur on serious limitations when the analysis need to be expanded beyond just diffusion e.g. if one wants to develop a more complex model with markets to capture other agents - such as firms - decision making processes. This is true because of the fact that agents does not have mobility on

[21] A decision taken cannot be changed during time.
[22] See Park and Lessig (1981).
[23] See Markiewicz (1974).
[24] See Kollat and Willet (1964).
[25] Whether they are consuming product A or B.

SWNs[26] and thus the possibilities for modelling interactions with other types of agents or with the environment is severely limited[27].

2.3.2 Spatial Dynamic Awareness Model (SPADA)

We propose a new approach to agents interaction in which agents (nodes) are not static, i.e. they randomly move around across a bi-dimensional wrapped[28]plain. By doing so, agents are always changing their relative positions to other agents and thus have the opportunity to interact with different sets of neighbours at each point in time. Neighbourhood of a given consumer i at time t in this case is defined not by previously randomized edges, but by the set of other agents currently inside consumers i awareness at time t.

We define the awareness[29] of an agent i as a circle of radius Λ around the centre of agent i that captures his capability to perceive and draw information from other agents and from the environment around him[30].

Imagine an individual in the metro heading to work. He might be paying attention to the people standing or sitting next to him but he might also be distracted drowned in thoughts about job or family or just texting something on his cellphone, for example. These two different scenarios yields two different awareness radius. In the second case, for example, he might miss the fashionable new high-tech smartphone another individual in the same wagon, but sitting a bit distant from him, is using, but he will probably notice it if the individual is standing or sitting right next to him.

Consider now that he did see the other individual smartphone. It might fit his personal technological tastes perfectly, causing him to rush to a smartphone store to buy it on the very same day. In this case, awareness played an important role on innovation diffusion even without any social pressures, because the adoption of the new product by our test subject happened exclusively because of his personal tastes. Now imagine that our subject is fond of technology, but not so desperate to acquire new expensive products right when he sees it. As time passes and he catches the same train to go to work or any different train to get wherever, chances are that he will see more and more different people wearing the same phone and might decide that is time to switch his outdated phone by a state of the art one.

This time our little wagon interaction, if the readers pardon the pun, yielded a bandwagon behaviour, but one that has little to do with his social network[31].

[26]Small World Networks.

[27]There are other possibilities such as the use of evolutionary NK models. See Valente (2008) for more information on NK-based models.

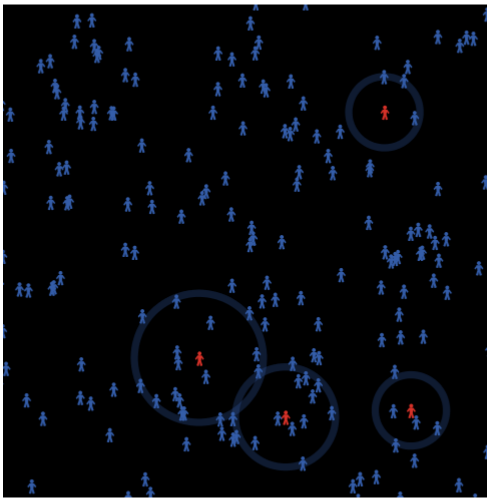
[28]When an agent cross any of the boundaries of the plain he arrives at the other side.

[29]For more information about awareness in social sciences see Chugh and Bazerman (2007).

[30]Another advantage of the SPADA model is that, since there are no directed or undirected edges, it allows for easy modelling of different influential weights between agents in the same neighbouring set.

[31]One can argue that the concept of social networks might cover the set of all people a given agent meets, but that is quite unrealistic and broad.

Figura 2.5: Awareness Radius Forming a Neighbouring Set



Awareness can be heterogeneous regarding individuals and time. The framework in figure 2.5 shows examples of heterogeneous consumer awareness radius yielding different neighbouring sets of different sizes. Bandwagon pressures may arise from both the total amount and the percentage of people who adopted a certain product in the neighbouring set.

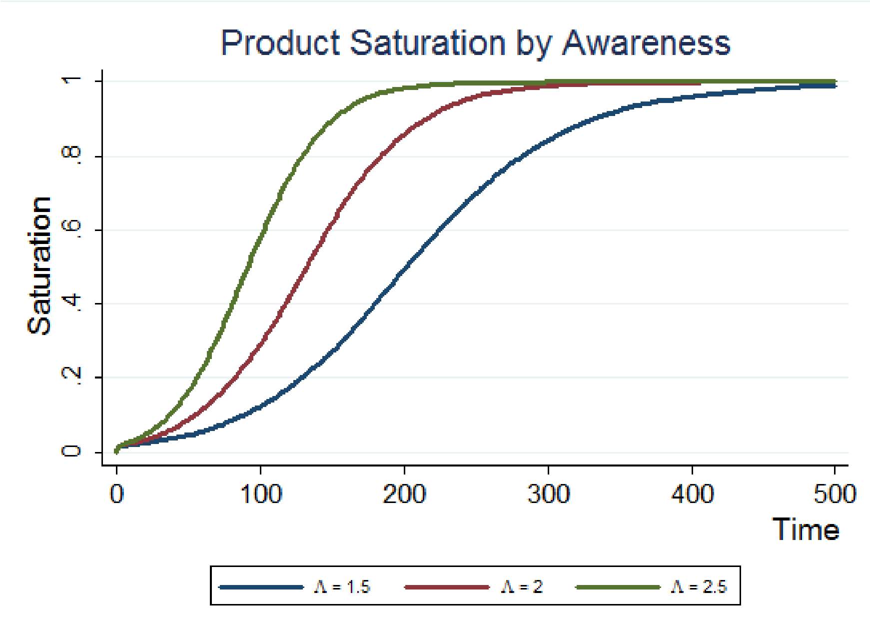
Consider a set of consumers with normally distributed heterogeneous preferences towards the adoption of new technologies, given by β, and homogeneous awareness radius Λ that are randomly spread across a bi dimensional wrapped plain Γ. Consider also that the set of consumers who already adopted a recently released new technological product z is given by Φ_z. At any point in time t, the neighbouring set of individuals who can potentially influence a given consumer i is given by $\Omega_i(t) = \{j \mid (j,i) \in \Lambda_i\}$, where j comprises all of the individuals in range of consumer i awareness. Consumer is influenced both from the amount and percentage of neighbours who have already adopted. Decision process is given by:

$$\beta_i \left(\alpha \frac{|\Phi z(t) \cap \Omega i(t)|}{|\Omega i(t)|} + (1-\alpha) \, |\Phi z(t) \cap \Omega i(t)| \right) > \upsilon \Rightarrow i \in \Phi z(t+1) \qquad (2.5)$$

where $0 \leq \alpha \leq 1$ is a constant denoting the weights for total and percentage of adopters and υ is a random number drawn from an uniform distribution between 0 and 1. Also note that the bars surrounding the numerator and denominator of the first term on the left denotes cardinality i.e. the number of items inside each set.

Figure 2.6 below show simulation results of the model diffusion pattern for different consumer awareness radius values. We can clearly see that innovation diffusion follows the traditional Product Life Cycle S-shape and that as rationality increases do does diffusion.

Figura 2.6: Results From SPADA Model



There are several ways in which SPADA model can be expanded to fit different formats of interaction. One may argue, for example, that even though the different daily interactions and environment perceptions we incur every day are important to shape bandwagon behaviour, social networks such as family, friends and colleagues have a stronger impact on shaping ones decision. A simple modification of the model handles this concern.

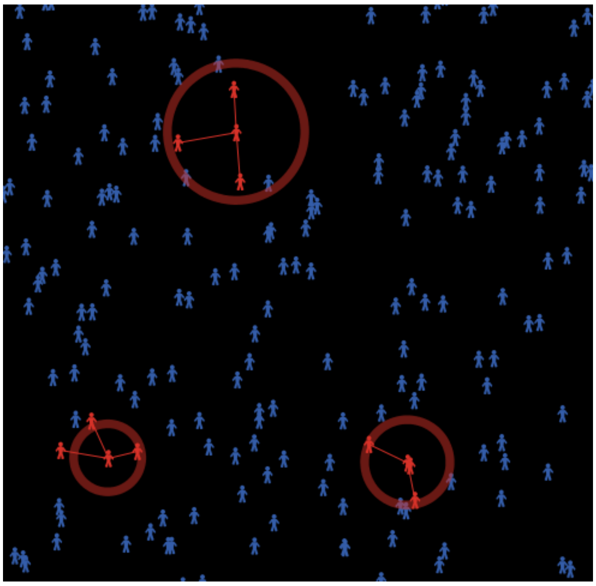
Consider that $\Theta_i = \{j|(j,i) \in \epsilon\}$ is the set of neighbours of agent i connected by the set of edges ϵ representing an individual social network. For simplicity, also consider that this time consumers can only be influenced by the percentage of consumers they know who already adopted the product (and not by also the amount). Consumer decision will be given by:

$$\beta_i \left(\kappa \frac{|\Phi z(t) \cap \Theta i(t)|}{|\Theta i(t)|} + (1-\kappa) \frac{|\Phi z(t) \cap \Omega i(t)|}{|\Omega i(t)|} \right) > \upsilon \Rightarrow i \in \Phi z(t+1) \qquad (2.6)$$

where $0 < \kappa < 1$ is the chosen weight for social network interaction.

Figure 2.7 below exemplifies the awareness + social network connections:

Figura 2.7: Agents Forming Neighbouring Sets Through Awareness And Edges



Finally, SPADA model can also feature a system of learning and forgetting. As in our bandwagon smartphone example from before, an individual might accumulate the experiences of meeting other agents who already adopted a new product and build up the will to acquire it himself. However, it is safe to assume that our individual will not be able to keep exact track of how many adopters he has seen because of memory limitations. For simplicity, we can assume that this becomes a continuous process, other than discrete. Recall that $|\Phi z(t) \cap \Omega i(t)|$ is the amount of agents in awareness radius Λ_i of consumer i that have already adopted a new technology. Thus, the process of accumulating and forgetting bandwagon experience can be viewed as:

$$E_i(t+1) = |\Phi z(t) \cap \Omega i(t)| - \delta E_i(t) \tag{2.7}$$

where E_i is the accumulated bandwagon experience and $0 < \delta < 1$ is the forgetting rate (memory loss) of consumers.

Capítulo 3

The Echoes of Bandwagon Through a Complex System of Innovation and Development

More than 100 years after the seminar work of Schumpeter the study of innovation still holds some important uncovered topics of research, specially regarding more complex subjects such as how demand heterogeneity and the real behaviour of agents affects its size, rate, type and diffusion. In this chapter, we seek to contribute to the literature analysing how preferences guided by bandwagon behaviour may affect innovation decisions. More specifically, the decision of a firm to choose between process and product innovation given the state of the market. Due to the degree of complexity involved in the matter, we choose to build an agent-based model where agents have bounded rationality and sequentially make non maximizing decisions based on the amount of information they have about the market. The rationality degree can be exogenously adjusted setting the awareness capability of consumers. As a core of bandwagon behaviour, each consumer is affected by the decision of others and the resulting cascade effect yields different impacts on the economy depending on the inclination of each agent towards new products. There are in total five types of consumers: techies, visionaries, pragmatists, conservatives and skeptics, in decreasing order of bandwagon behaviour degree. We find that the greater the number of techies, the faster is the saturation and de-concentration of the market, generating more product than process innovations, higher mean prices and profits of firms.

3.1 Introduction

Dating back from Schumpeter (1934), literature on innovation has evolved to the point of leading its object of study to the status of one of the main forces driving economic growth and development. The fact that Sollow TFP[1] black box might not be so black anymore has certainly something to do with understanding how the engine of innovation is greased. In this paper, we suggest that one of the cogwheels of this

[1] Total Factor Productivity.

engine is the bandwagon behaviour of consumers, its impact on innovation diffusion and, ultimately, on the firm's decision to engage on a certain type of innovative process.

Bandwagon effect was first introduced by Leibenstein (1950) based on previous contributions of past economists, psychologist and sociologists, such as Veblen (1899), Rae (1905) and Morgenstern (1948), in the phenomena of fashion and conspicuous consumption. Developments of this field in innovation literature yielded sophisticated formal threshold models of innovation diffusion through social networks from both the supply and demand points of view, especially Granoveter (1978) and, more recently, Rosenkopf and Abrahamson (1999), Young (2002) and Acemoglu et al. (2011).

The recent increase in computational capacities and its popularization in economics are key factors to understand why these subjects are back on the spotlight. Demand heterogeneity suits itself much better in complex environments and models that cannot yield useful solutions other than through simulation. It is also very hard to fit consumer interaction into equilibrium models which only reinforces the need of proper agent-based models to capture all the nuances behind it.

With all this information at hand, it is perfectly arguable that the product cycle theory ruled by the triad Vernon (1966) - Utherback and Abernathy (1978) - Kotler (2005) might be outdated or in need of some re-discussion. A lot has changed since VHS and innovation is now viewed more as a survivability necessity than a profit maximization luxury. New high-tech products such as smartphones, TV's and computers presents a much higher rate of creative destruction. Product innovation does not seem to slow down as predicted by the first two Life Cycle theories yielding great differentiation that creates changes ranging from small, to ones big enough to challenge the dominant design. The fact is that these industries cannot rely on market expansion, already saturated, and even less on repeated purchases given how durable the products are.

The only solution is then to engage heavily on R&D[2] to be able to sustain a constant de-maturity process (see Higuchi and Trout (2008)) in which consumer bandwagon behaviour plays a key role to success. The bandwagon behaviour was described by Moore (2005) and its details will be stretched further.

Have you ever seen those hundreds of kids camping outside malls to be the firsts to put their hands on new Iphones? According to Moore (2005) they are called *techies* and correspond to about 2.5% of the consumers. They are followed by *visionaries* (12.5%), *pragmatists* (35%), *conservatives* (35%) and *skeptics* (15%), in decreasing order of appreciation towards new technology.

We propose to take the next step in bandwagon theory regarding innovation and investigate how the emergent pattern of diffusion from consumers bandwagon effect shapes the market and influences the firm decision between process and product innovation. This interactive behaviour is determinant to understand how the speed of technological change shape societies and promotes economic development and welfare.

In order to do so, we build an agent-based model where consumers have bounded rationality and sequentially make non maximizing decisions about buying only one product from the available firms. Consumers are heterogeneous in respect to what we call *profile* towards new products and follow the distribution proposed by Moore (2005) as

[2] Research and Development.

a baseline. Since our consumers do not have information about global demand or preferences, the probability to change consumption choices plays the role of thresholds. Consumers can only get information about quality and prices by interacting with each other when they are inside each other's awareness radius (similar to Chugh and Bazerman (2007)). Consumers then evaluate how many others are using a given product or technology and decide to change their product of choice or not. Firms on the other hand cannot see individual preferences, but analyse market saturation and concentration to decide on the amount of R&D investment and between process and product innovation.

The type of innovation intended to be modelled in this present chapter and in the subsequent one is incremental innovation at a high-tech industry. The Product Life Cycle generated by the model does not intend to fit all industries and most certainly not the entire life cycle of a given industry from birth to death. Again, we are concerned with the dynamics of incremental innovations that generates different products and versions of products such as the Iphone series example already pointed out in this document.

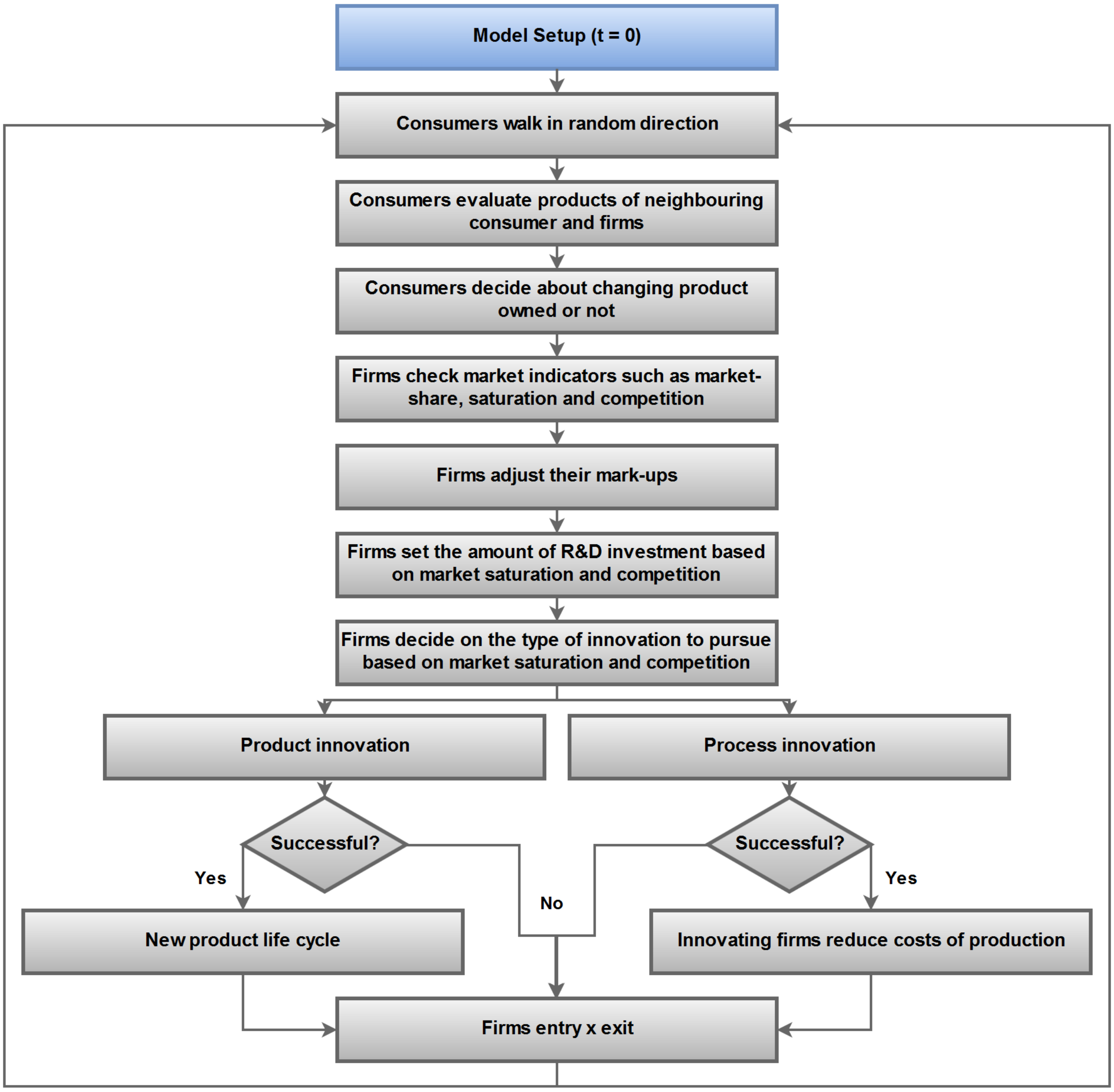
The chapter is organized as follows: section 3.2 presents a formal agent-based model in which consumers have bandwagon behaviour and influences process and product innovation decision by firms. Section 3.3 presents and discusses the results and, finally, section 3.4 brings the conclusions.

3.2 The Model

In this section we present a formal agent-based model based on the SPADA framework described in chapter 2 where consumers have bounded awareness and sequentially make non maximizing decisions about buying only one product from the spectrum of available firms. Consumers are heterogeneous in respect to what we call *profile* towards new products and follow the distribution proposed by Moore (2005) as a baseline. Since our consumers do not have information about global demand or preferences, the probability to change consumption choices plays a stochastic role of traditional deterministic thresholds. Consumers can only get information about quality and prices by interacting with each other when they are inside each other's awareness radius[3]. Consumers then evaluate how many others are using a given product or technology and decide to change their product of choice or not with probability ϕ. Firms on the other hand cannot see individual preferences, but analyse market saturation and concentration to decide on the amount of R&D investment on each period t and between process and product innovation. There are strong interactions between consumers and consumers, and consumers and firms which produce complex dynamics of innovations, cycles and economic development. The cyclical sequence of steps of the simulation model is described in figure 3.1 below:

[3]Similar to Chugh and Bazerman (2007) and Ellison (1993).

Figura 3.1: Sequential Steps of The Simulation Model



A table (table A.1 containing a brief explanation of all variables described in the model as well as the simulation codes can be found in Appendix A and B at the end of the document.

3.2.1 Consumer Interaction and Bandwagon Behaviour

Consider a constant length set of consumers given by $\Omega = \{1, ..., N\}$ with heterogeneous profiles (propensity to assimilate new technologies or products) that follows a quasi-normal distribution in respect to their probability of incidence in the population described in table 3.1 below. Each consumer ω_i carries an intrinsic propensity to adopt new products according to their profile, which we call stochastic bandwagon threshold

(β). Consumers are randomly spread and randomly move across a bi-dimensional wrapped plain Γ characterizing our economic space.

Tabela 3.1: Bandwagon Population

Type	% of population	β
Techies	2.5	1
Visionaries	12.5	0.8
Pragmatists	35	0.6
Conservatives	35	0.4
Skeptics	15	0.2

Consumers have the same bounded awareness represented in the model by a circle of radius $\Lambda \subseteq \Gamma$ around them[4].

Consumers can also die with the probability $k_4 \in [0, 1]$, but they immediately give birth to another agent with the same profile, the only difference being that new consumers enter into the space Γ with no supplier[5]. This mechanism is introduced in order to capture the effects of new agents constantly entering the market. since they have no information whatsoever about products prices and quality they are important to contribute to smaller firms demand and thus prevent monopoly situations. The set of consumers at time t, $\Omega = \{1, ..., N\}$ as well as its distribution is, nevertheless, always kept constant[6]

At any point in time t, consumers may own only one product z of quality q, supplied by firm $x \in \{0, ..., X\}$ for which they pay the price ρ.[7]. However, they can be influenced to change their adopted product if they are inside each others awareness radius i.e., if they are neighbours with relative position between $(\omega_i, \omega_j) = (0, 0...\Lambda)$ in the plain. In this coordinate 0 means the reference point where the consumer stand, from which he or she can see by a distance of radius Λ. The neighbouring set of individuals who can potentially influence consumer $i \in \Omega$ in time t can then be described as $\Theta_i(t) = \{j \mid (j, i) \in \Lambda_i\}$, where j comprises all of the individuals in range of consumer i awareness (Λ_i). The consumers j inside the view radius of consumer i carry some information which can convince or not he or she buy the new product. For example, it can happen that a consumer j be a *skeptic* who not bought a new technology yet, therefore, do not carry information about quality q and price ρ of a new product.

We assume that at the initial state of the model $t(0)$ there is only one incumbent firm that invents a brand new type of high-tech product and immediately engages in marketing activities capturing all consumers with a *techies* profile. These "crazy for technology" consumers will also instantly buy any new better quality versions of the

[4]Note that this is not the same radius suggested by Young (2002) in his model where agents are distributed along the edges of a radius.

[5]And consequently without a product, quality, price paid and so on.

[6]This is a necessary condition to analyse how changes in the distribution (more precisely the number of *techies*) affects the evolution and final stage of the model during simulation.

[7]We choose to make two distinctions about notation: between the price paid by a consumer ρ and the price charged by a firm p; and between the consumer product provider χ and the firm per se x.

product provided they are clients of the innovating firm at the time of product innovation[8]. At time t the subset of consumers who adopted a given product z in the market is given by $\Phi_z(t) \subseteq \Omega$.

A consumer $i \notin \Phi_z(t)$ may be influenced once per time by his neighbours to change his product in two distinct situations: when faced with one or more neighbours j who have adopted: a) a better quality product; or b) a product of the same quality from a firm with a lower price. If there is more than one different product quality perceivable from Λ, Consumer i will only consider to change for the best one.[9]

Adoption by quality

We will start by addressing the first case. A consumer $i \notin \Phi_z(t)$, walking randomly through our plain, meets in his awareness radius Λ at least one neighbour who owns a better quality product $z_j > z_i$. The probability that consumer i will be influenced to buy the better-quality product he saw will be affected by three factors: the amount and percentage of the neighbours owning that product at time t and consumers i bandwagon profile. The decision process is detailed below. Note that the bars delimiting the terms in the numerator and denominator of the first term of the equation denotes cardinality i.e. the number of agents on each of the sets. The decision is:

$$\beta_i \left(k_1 \frac{|\Phi z(t) \cap \Theta i(t)|}{|\Theta i(t)|} + (1-k_1) \frac{1}{1+e^{-|\Phi z(t) \cap \Theta i(t)|}} \right) > \epsilon \Rightarrow i \in \Phi z(t+1) \tag{3.1}$$

where ϵ is a random number following a continuous uniform distribution over the range $\epsilon = U[0,1]$ and $\{0 \leq k_1 \leq 1\}$ is a constant measuring the impact of each type of influence. Note that the second term inside the parenthesis on the left side of the equation has a sigmoid shape to ensure values between 0 and 1.

Now[10]. consumer i is left with the decision of where to buy the product, i.e. from which one of the available firms. If there is only one candidate $j \in \Lambda_i(t)$ for potential influencer in consumer i awareness radius Λ_i, the decision is straightforward and he will buy from his neighbour's supplier so that $\chi_i(t+1) = \chi_j(t)$. However, in cases where the subset $\Phi z(t) \cap \Theta i(t)$ is non-unitary, it may be possible that there will be two or more neighbours who are clients of different firms. How will consumer i choose between the available firms? He will choose to buy the selected product from the firm that incurs him the lowest effort e_i. The effort of a given consumer i to buy a product z from a provider firm χ is given by:

$$e_i = \rho_{i,\chi} + k_2 d_{i,\chi} \tag{3.2}$$

[8]Techies will always act as seeders of the new versions of the product.

[9]Pay close attention to the fact that consumers will also always prefer a quality change over a price change in the form: $q \succ \rho \Leftrightarrow (q \succ \rho \bigwedge q \nprec \rho)$. i.e., there is no utility function in the model in the form of a trade-off between quality and price because consumers are assumed to have enough income to buy any product they want. We shall discuss income inequality later in this thesis.

[10]From here on we will drop the time notation when it is not necessary.

where ρ_i is the price paid by agent i for product z_i of firm χ_i at time t, d_i is the distance between the consumer i and his supplier χ_i and $0 \leq k_2 \leq 1$ is a constant measuring the impact of distance on a consumers effort.

But consumer i does not have information about the prices of all firms in Γ, therefore he will need to choose based on the effort information gathered from his neighbours $j \in \Lambda_i(t)$. The firm χ choose by consumer i will depends on the interacting process given by:

$$\chi_i = \arg\min_{\chi}\{e_j(\chi_j) \mid \chi_j \in \{1, ..., X\}; j \in \Lambda_i(t)\} \tag{3.3}$$

where $e_j(\chi_j)$ is the effort the consumer i must incur to reach a firm (χ_j) into its view radius (Λ_i).

Adoption by price

Now consider the second setting of interaction between consumers in which $\Phi z(t) \cap \Theta i(t) = \emptyset$. In this case, consumers bandwagon behaviour neither the amount and percentage of neighbours who owns a product with a lower price matters because they are not analysing a change in product quality/technology. However, we assume that there is an associated cost in changing the firm providing products for consumer i and thus changing is not guaranteed, but depends positively on the difference between the price paid by him ρ_i and by consumer ρ_j[11]. Consumer i will ultimately change his supplier χ_i if his new effort $e_i(\rho_j, \chi_j)$ is lower than the current one $e_i(\rho_i, \chi_i)$. The interaction results in:

$$\chi_i(t+1) = \chi_j(t) \quad \text{if} \quad (1 - \frac{\rho_j}{\rho_i}) > \epsilon \quad \text{and} \quad e_i(\rho_j, \chi_j) < e_i(\rho_i, \chi_i) \tag{3.4}$$

Besides being influenced by neighbours, consumers can also be influenced by firms inside Λ_i. The set of firms that can influence consumer i at time t is given by $\Xi_i(t) = \{x \mid (x, i) \in \Lambda_i\}$[12]. Similarly to the pure consumer interaction there are two ways in which a firm may influence a given consumer i to change his product: a) there is at least one firm x in Λ selling a product with a better quality than z_i; and b) there is at least one firm offering a product with the same quality as z_i but for a lower price.

In the first scenario, consumer i finds a firm x with a better quality product $z_x > z_i$ than he has and is influenced to buy it. The decision whether to adopt or not adopt this product and supplier will depend solely on consumer i bandwagon profile according to:

$$\beta_i k_3 > \epsilon \Rightarrow z_i(t+1) = z_x \quad \text{and} \quad \chi_i(t+1) = x \tag{3.5}$$

where $0 \leq k_3 \leq 1$ is a constant.

[11] As in the previous case consumers will only consider to be influenced by his neighbour with the lowest price.

[12] Note, though, that individuals cannot interact with buildings so we assume that the interaction occurs between a consumer and a salesman trying to convince him to buy the latest best-quality product of the firm.

If the set $\Xi_i(t) = \{x \mid (x, i) \in \Lambda_i\}$ is non unitary, there might be two or more firms charging different prices p_x for products with the same quality. In this case consumers will always prefer the firm offering product with the lowest price:

$$\chi_i = \arg\min_x \{p(x) \mid x \in \{1, ..., X\}\} \tag{3.6}$$

The second setting presents the case in which a consumer owning a product with quality q_i finds a firm x selling the same product for less money i.e., $p_x < \rho_i$. Analogously to the pure consumer interaction consumer i will decide between changing his supplier or not based on the difference between the price he is paying for the product and how much the firm is selling it for:

$$\chi_i(t+1) = x \quad \text{if} \quad (1 - \frac{p_x}{\rho_i}) > \epsilon \tag{3.7}$$

3.2.2 Firm Behaviour

As mentioned in the previous section, at time $t(0)$ only one incumbent firm[13] creates a new economic sector or market[14] by inventing a product and immediately captures the demand of *techies*. From this point on new firms can enter and exit the market if they find it profitable, considering the option of investing in bonds paying the constant interest rate r. Thus at a given time $t \neq 0$ there will be a set $F = \{1, ..., X\}$ of firms in the market. Firms produce goods on-demand and thus doesn't accumulate stocks. There is also no kind of economies of scale or scope i.e., cost reduction arises only from successful process innovations.

There are two pivotal decisions a firm has to make in the model: how much to spend in research and development activities and what type of innovation to pursue given the market situation at any point in time. Based on the literature, we assume that market saturation and competition play a key role on a firm innovative decisions.

R&D expenditures decision

Despite Schumpeter's claim that monopoly power provides incentives for innovation by raising the firm's capabilities, recent literature on the subject[15] shows that it is usually competition that fuels innovation. The argument is that competition raises the intrinsic costs of falling behind in competitiveness by failing to successfully engage on R&D activities. Aghion et al. (2002) finds that these two effects combined generates an inverted-U relationship between the variables. Up to a certain level, competition creates incentives for innovation because firms try to become more competitive reducing costs or differentiating products, but if competition gets to fierce, profits tend to fall along with resources available for R&D. In our model we assume that investment in R&D is a

[13]Adding more incumbent firms does not change the outcome of the model except for the initial HHI concentration index.

[14]The new sector can be view both as industry or service.

[15]For more details about the relationship between competition and innovation see Aghion et al. (2002), Aghion et al. (2006) Tomohiko et al. (2008)

positive function of competition but since the amount invested is given by a percentage of profits, competition might hinder innovation if it heavily impacts profit.

Pasinetti (1981) has long ago stated that saturation is a natural bottleneck for economic growth and development. Even in the case of a incredibly high and sustainable productivity growth, population would have to grow accordingly for saturation not to happen, which does not seem to be the case for most developed and developing countries. The way firms deal with saturation is through a life cycle de-maturity process of product innovation, specially in durable goods industry where re-buying takes time to occur. McMeekin et al. (2002) provides a great overview of the literature relating aspects of demand with innovation. We use Saviotti and Pyka (2012) equation that relates search activities with market saturation[16] and a similar function to competition impact on innovation to define the percentage of profits a firm will secure for R&D at any point in time:

$$\theta_x = k_4(1 - e^{(-k_5 S_x)}) + k_6(1 - e^{(-k_7 \mathrm{HHI})}) \tag{3.8}$$

where θ_x is the chosen percentage of profits secured for R&D, $0 < k_{4,\dots,7} < 1$ are constants, HHI is the Herfindahl Hirschman Index and S_x is the market saturation for the best-product of firm x. HHI and S_x are given by:

$$S_x = \frac{\sum_{i=1}^{N}[C_i \mid z_i = z_x]}{\sum_{i=1}^{N}[C_i \mid z_i \neq 0]} \tag{3.9}$$

$$\mathrm{HHI} = \sum_{x=1}^{X} ms_x^2 \tag{3.10}$$

where ms_x is the market-share of firm x. Thus the investment in R&D of firm x at time t is given by:

$$I_x^{R\&D} = \theta_x \pi_x \tag{3.11}$$

with

$$\pi_x = \sum_{z=1}^{Z}(D_x(p_x - c_x) \tag{3.12}$$

where π_x is the profit, D_x, p_x and c_x the demand, price and cost for each product of firm x.

Innovation type decision

After deciding on the amount of R&D resources, firms have to decide in what type of innovation firms are going to invest these resources. It is reasonable to assume[17]that

[16]It is important to note that firms will always consider the saturation of their best-quality product for innovation decisions and not the global saturation level

[17]This is a subject yet to be better explored by the literature since results are still inconclusive. Some examples of papers in this area are Bonanno and Harworth (1998) and Rosenkrantz (2005).

market saturation has a bigger impact on product innovation than process innovation because a firm can only overcome saturation with process innovation while there is still a potential demand to be conquered. However, it is a little more complicated to infer the contrary for market competition, since both product and process innovation can help a firm to gain a competitive advantage[18]. Nevertheless, we assume that firms will prefer to invest in product innovation only when market saturation is higher than market competition and saturation is above a certain threshold S_{min}. This is due to the fact that product innovation is considered to be more difficult to successfully implement than process innovation, since it requires consumers approval.

$$\text{Type} = \begin{cases} \text{Product} \Rightarrow I_x^{R\&D}(t) = I_x^{PD}(t) & \text{if} \quad S_x(t) > H(t) \quad \& \quad S_x(t) > S_{min} \\ \text{Process} \Rightarrow I_x^{R\&D}(t) = I_x^{PC}(t) & \quad \text{otherwise} \end{cases} \tag{3.13}$$

where PD means product innovation and PC process innovation. The probability of arrival of an innovation type is a linear function of the total amount of investment in one of them. It follows that:

$$\phi_x^{PD,PC} = k_8^{PD,PC} I_x^{PD,PC} \tag{3.14}$$

where $0 < k_8^{PD,PC} < 1$ are constants.

Effects of successful innovations

We now turn our attention to how a successful innovation changes the innovating firm status. Consider first the case of product innovation. When a firm manages to succeed in product innovation in time t, it uses all it's R&D resources of that type[19] to start producing, at $t+1$, a new product of better quality than its previous best ($Q_{z,x}(t+1) > Q_{z,x}(t)$), at a higher cost ($c_{Z,x}(Q,t+1) > c_{Z,x}(Q,t)$) that will be added to the set $\Psi_x(q,t) = \{1, ..., Z_Q\}$ of all products, ordered by their quality, being demanded to firm x. The new product is immediately adopted by the firm x set of "techies" clients[20]. We can summarize the impact of a product innovation as:

$$\phi_x^{PD} > \epsilon \Rightarrow \begin{cases} Z_{Q,x}(t+1) \in \Psi_x(t+1) \\ Q_{Z,x}(t+1) = Q_{z,x}(t) + (\Delta_q) \\ c_Z(Q,t+1) = (\Delta_c^{PD}) c_Z(Q,t) \end{cases} \tag{3.15}$$

where it is assumed that Δq[21] and Δ_c^{PD}[22] are constant in time parameters measuring the impact of product innovation on Q_Z and c_Z respectively.

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[18] See Porter (1999).

[19] In this case I_x^{PD}.

[20] If a firm does not possess any costumer with techies profile the only way it can diffuse the new innovation is through consumer/firm interaction.

[21] We assume $\Delta q = 10$ although it may take any positive value without changing the outcome of the model.

[22] We follow Adner and Levinthal (2001) and assume $\Delta c = 0.2$.

Process innovation, on the other hand, has the sole effect of reducing the cost of production of all of a firms products:

$$c_z(t+1) = \Delta_c^{PC}[c_z(t)] \quad \text{if} \quad \phi_x^{PC} > \epsilon \tag{3.16}$$

Price setting behaviour

Firms are engaged in Bertrand competition defining their prices primarily by a mark-up rule, but also considering the mean price of firms in the market when $|\Xi| > 2$. We assume that prices are somewhat sticky, meaning that firms will wait a certain threshold number of periods (τ) before reacting to market-share (MS_x) alterations in order to assay if the tendency is persistent or seasonal.[23]. The price $p_{z,x}$ charged for product z of quality q by a firm x at time t is given by:

$$p_{z,x}(t) = \begin{cases} \mu_x(t)c_{z,x}(t) & \text{if} \quad |\Xi| \leq 2 \\ k_9\mu c_{z(q),x}(t) + (1-k_9)\frac{\sum_{x=1}^{X} p_{z,x}}{|\Xi|} & \text{if} \quad |\Xi| > 2 \end{cases} \tag{3.17}$$

where $\mu_x(t)$ is the mark-up of firm x at time t and $0 < k_9 \leq 1$ is the impact of mark-up on a firms price decision[24]

Firms alter their mark-up according to:

$$\mu_x(t) = \begin{cases} \mu_x(t-1) + k_{10}\mu_x(t-1) & \text{if} \quad MS_x(t-\tau) < MS_x(t-\tau+1).... < MS_x(t) \\ \mu_x(t-1) - k_{10}\mu_x(t-1) & \text{if} \quad MS_x(t-\tau) > MS_x(t-\tau+1).... > MS_x(t) \end{cases} \tag{3.18}$$

where $0 < k_{10} < 1$ is the mark-up changing reaction.

Entry/exit mechanism

At any point in time a prospective firm faces the decision of entering given the market situation. In order to make the decision, it is assumed that possible entrants observe the mean profit rate of currently operating firms, the saturation of the best-quality product and the concentration of the market. The higher the market profits and concentration and the lower the saturation, higher the probability to enter[25]. Entrants will only be willing to produce the best-quality product in the market at time of possible entry. Additionally, the saturation of the chosen product cannot be higher than 50%[26]. Best-quality product saturation is given by:

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[23] Due to managerial costs such as menu, customer negotiation and information gathering costs. See Zbaracki et al. (2003) and Dias et al. (2011) for a detailed discussion.

[24] Simulating the model we will assume that $k_9 = 0.6$ based on studies of Keney et al. (2010) who finds that the share of firms that set their prices by mark-up is about 60% while 40% of firms set their prices by looking at the other firms prices.

[25] See Dixit (1989) and Chang (2009) for studies about firm entry/exit decision.

[26] We assume a firm will never be willing to enter the market producing a good that is close to maximum saturation because the entrant won't have time to accumulate R&D investment for product and process innovation and will most likely fall behind on technology and product quality.

$$S_Z(t) = \frac{\sum_{i=1}^{N}[\omega_i \mid z_i(t) = Z(t)]}{N} \tag{3.19}$$

where z_i is the product being consumed by consumer i.

The mean profit rate of firms is:

$$\overline{\varpi} = \frac{\sum_{x=1}^{X} \frac{\sum_{z=1}^{Z} \varpi_{z,x}}{Z}}{X} \tag{3.20}$$

where $\varpi_{z,x} = \pi_{z,x}/I_x$ is the profit rate of product z of firm x.

And thus the decision of a given firm to enter the market is given by:

$$\text{Entry} = \begin{cases} \text{Yes} & \text{if} \quad S_Z < 0.5; \quad \overline{\varpi} > r; \quad \overline{\varpi} S_Z H > \epsilon \\ \text{No} & \text{Otherwise} \end{cases} \tag{3.21}$$

Firms will exit the market if their mean profit-rate over a range T of periods is smaller than the interest rate r, which means firms fight to remain in the market even when profit-rates are smaller than the other possible investment option[27]. At any point in time a firm will check the mean of its last T profit-rates and compare it to the interest rate:

$$\text{Exit} = \begin{cases} \text{Yes} & \text{if} \quad \frac{\sum_{t=t-T}^{t} \varpi_x(t)}{T} < r \\ \text{No} & \text{Otherwise} \end{cases} \tag{3.22}$$

3.2.3 From micro behaviour to aggregated results

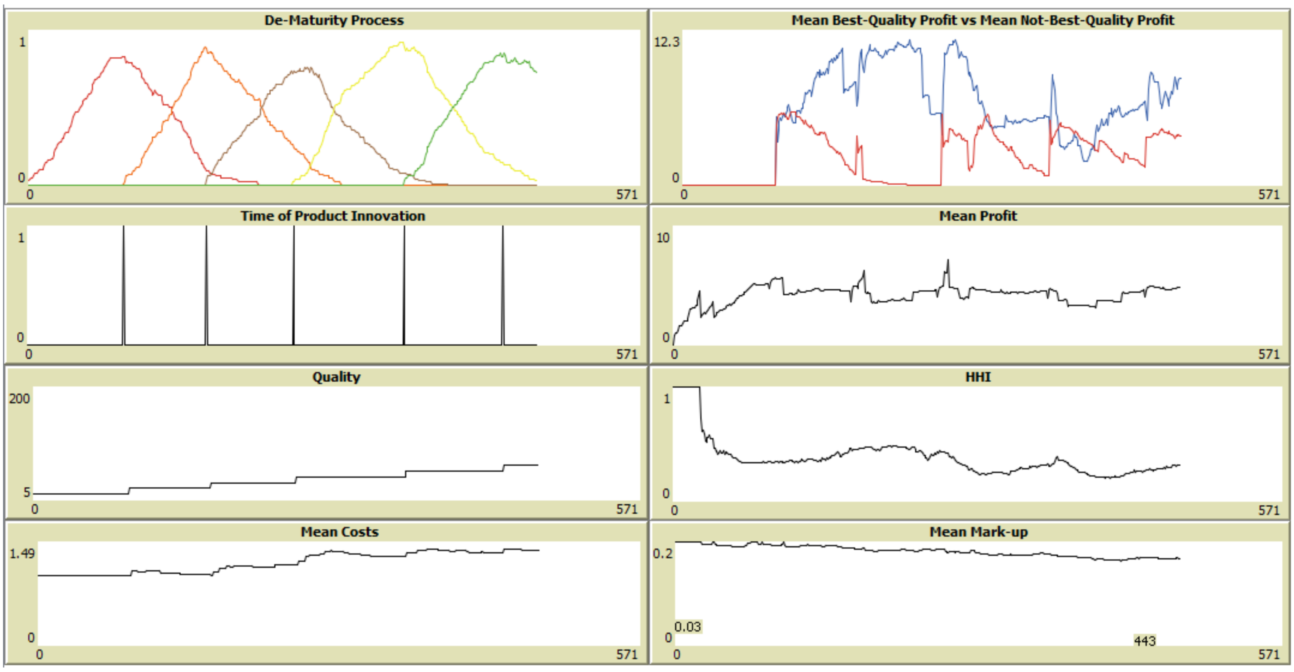
Before we go into the results of the model using a series of different simulation runs for each condition of interest, it is important that we analyse interesting macro patterns only observable when we consider a single simulation run, which means the resultant behaviour of variables is not a mean from several simulation runs. We are then able to shed some light in the "black box" that many consider agent-based models to be.

The figure 3.2 shows how the de-maturity process takes place in our economy and how some key variables such as quality and costs react to it. Note that saturation of a product of given quality - represented by the colourful lines[28] in the de-maturity graphic - follows a S-shaped curve as expected from empirical observations. Each time a new product is released demand saturation enters a new cycle as consumers are instigated by bandwagon behaviour to update the quality of their product. This creates degrees of product quality and costs, since each product innovation raises the mean cost of production by a small margin. We can also see the evolution of the mean profit between firms with the best quality in time t and the others as well as the mean mark-up and the Herfindahl-Hirschman concentration index.

[27] Is is assumed that there is no depreciation in the model which implies that a firm would be able to fully recover its initial investment I_x if they decided to sell their infrastructure.

[28] Only the first five product qualities are visible.

Figura 3.2: The Pattern of Variables on a Single Simulation Run



3.3 Results

In this section the simulation results of the model are presented in six different scenarios in which different values for two key variables are assumed: consumers awareness radius ($\Lambda = \{1.5, 2, 2.5\}$) and the percentage of techies amongst the population (techies $= \{3\%, 9\%, 15\%\}$). In order to ensure robustness, 100 simulation runs are performed for each scenario, for a total of 600 runs over a time period of $t = 2000$. Results are presented for every variable in the model, but the analysis focus lies on the evolution of market saturation, concentration, and the pattern of product and process innovation adopted by firms given market conditions. Similar to Adner and Levinthal (2001), it is possible to use the firms cost curve to evaluate the incidence of process and product innovation on each scenario given that firms cost is only affected by process (negative impact) and product innovation (positive impact). A positive relationship between cost and time indicates that firms have prioritized product over process innovation and vice versa. The models baseline is considered to be the case of techies $= 3\%$ and $\Lambda = 2$.

It will be shown that the impact of awareness radius and the percentage of techies in the proposed economy are quite similar, except for some few important peculiarities. However, it is fundamental to stress the complete difference between the logic and meaning associated with these two variables.

In this model, the awareness of an individual is a direct measure of rationality. If awareness radius is set to the maximum possible ($\Gamma/2$), that means consumers can perceive the consumption behaviour of every single agent in the economy at any point in time, which is rather unrealistic. But note though, that even so, it would not be possible to assume perfect rationality since the agents in this model cannot predict the future and foresee the decisions of consumers and firms alike. What can be safely argued is that awareness is a variable that probably does not change much from market to market. Of course, individuals have different interests and thus pay attention to different patterns of fashion but rationality is not expected to change that much and is probably not expected to be perfect.

The percentage of techies, on the other hand, simply refers to the amount of people in the economy that are willing to buy new products as soon as they are released and thus it is a variable strongly related to the degree of technology of the given market. It would be at least odd to watch people lining up early in the morning in front of the supermarket just to buy the new type of frozen lasagne a certain brand announced.

Table 3.2 below shows information about the values taken by constants in our model, which remains unchanged between scenarios:

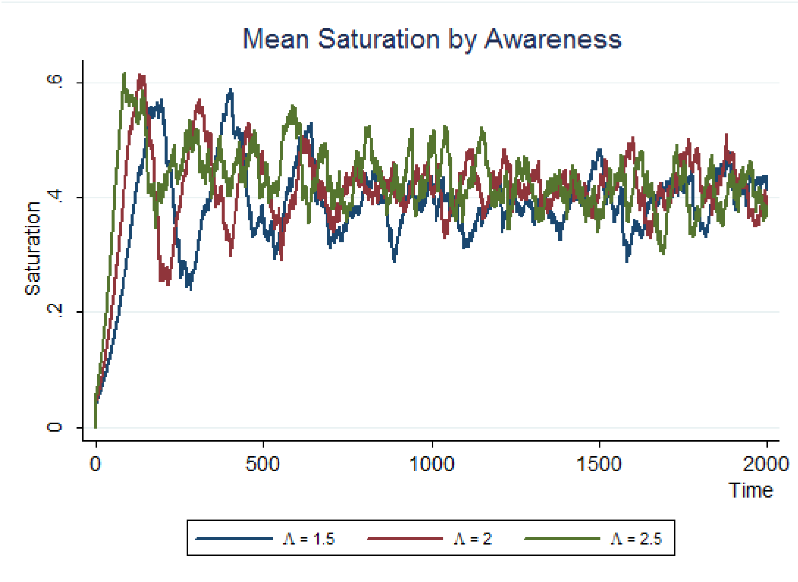
Tabela 3.2: Model Constants

Constant	Value	Constant	Value
Incumbents	1	Population	100
k_1	0.5	k_2	0.03
k_3	0.05	$k_{\{4,..,7\}}$	0.2
k_8^{PD}	0.01	k_8^{PC}	0.08
k_9	0.6	k_{10}	0.05
r	0.05	Δ_c^{PD}	0.2
Δ_c^{PC}	0.044	$c_{z,x}(0)$	1
$_x(0)$	0.2	$Q_Z(0)$	15

3.3.1 Varying Awareness

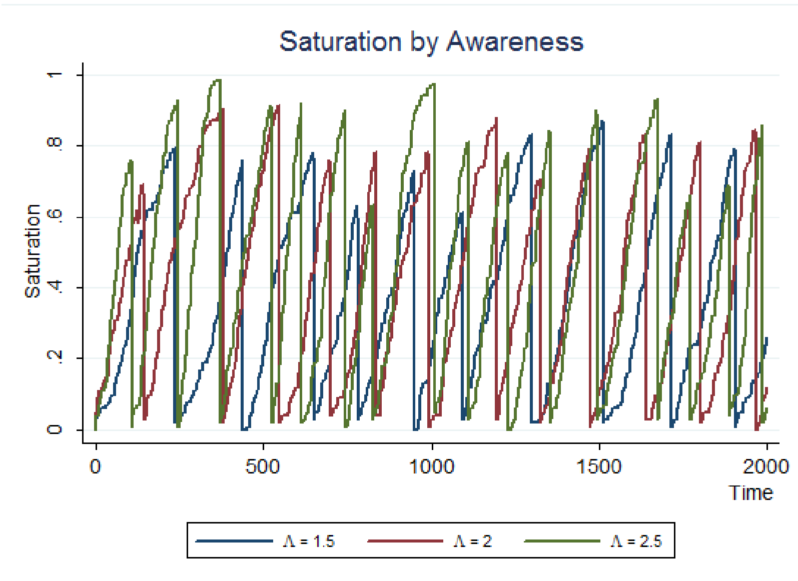
Changing the value of awareness radius has clear impacts over all variables of interest in the model. Lets start with the impact of awareness on market saturation. As mentioned in the previous section, there are certain variable patterns that are better observable when considering only one simulation run. Take saturation for example. Figure 3.3 below shows the mean best-quality product market saturation (S_Z(t)) of 100 simulations each point in time.

Figura 3.3: The Impact of Different Awareness Radius on Market Saturation (100 runs)



Since in every simulation the exact time of innovations arrival vary, it is difficult to observe product cycle and de-maturity patterns on aggregate simulations results. Nevertheless we can still observe that higher values of awareness yields saturation curves of higher frequency and higher spikes, indicating that awareness positively affects saturation speed and the maximum saturation achieved just before a new product innovation arrives. It is much easier to see this looking at just one simulation run[29] on figure 3.4:

Figura 3.4: The Impact of Different Awareness Radius on Market Saturation (1 run)

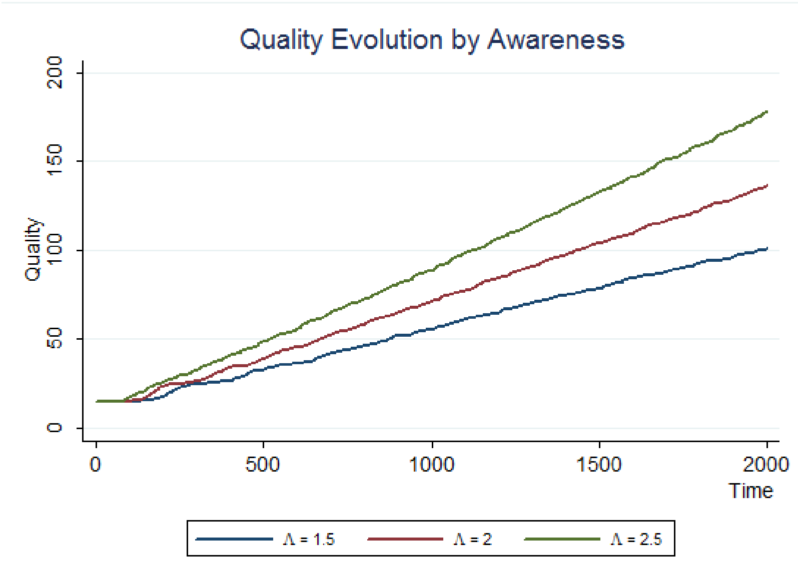


[29] Thus, we use simulations 1, 101 and 201 to create figure 3.4 from each awareness value on figure 3.3

With a bigger awareness radius Λ, or rationality, consumers are able to observe more individuals and therefore the probability to be influenced rises. Thus, a new product is diffused faster in the market raising the speed of saturation and consequently yielding more innovations along the observed period of time.

Figure 3.5 below that shows the evolution of quality in our economy for each Λ also confirms that.

Figura 3.5: The Impact of Different Awareness Radius on the Evolution of Product Quality



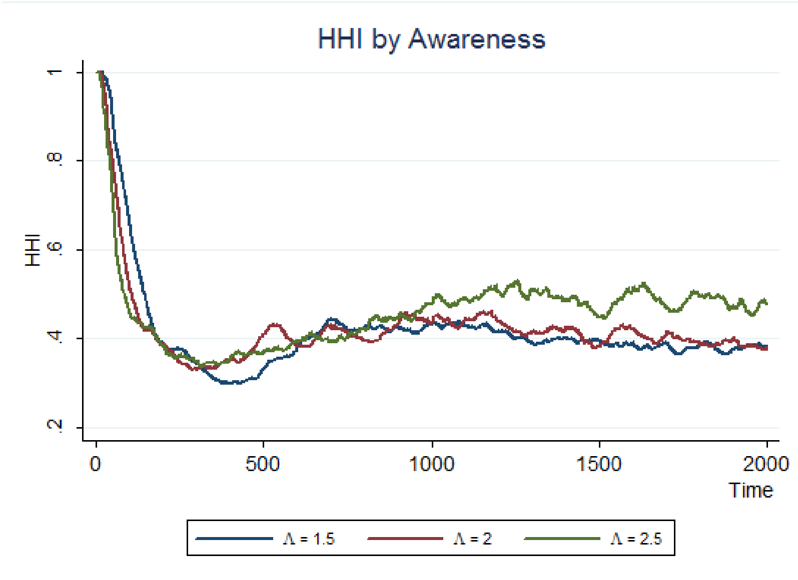
The higher the awareness the more frequent is the arrival of product innovations led by faster market saturation. Thus, the economy reaches higher product qualities. It can then be implied that growth and development are also higher, taking into consideration the important fact that there are no restrictions to technology, nor budget restrictions in our model.

The impact of awareness radius on market concentration is, however, not so straightforward because of the endogenous nature of the model. A higher awareness not only leaves consumers more susceptible to adopt new products, but also to pursue better prices. That means consumers will be changing suppliers more frequently which can be good for competition[30]. Additionally, since awareness affects saturation speed and maximum saturation before product innovation, it may leave a smaller time gap for firms to enter the market and start investing in innovation, providing some advantage to incumbent firms and even more to the firm that manages to be the first to create a new best-quality product. This also pressures firms to invest a bigger part of their profits on R&D, driving weaker firms out of the market.

Figure 3.6 below shows the effect of changing awareness on HHI.

[30]Mark-up adjustments will be more frequent raising price competition but not necessarily market competition because firms that fail to reduce their costs through process innovation will be punished harder.

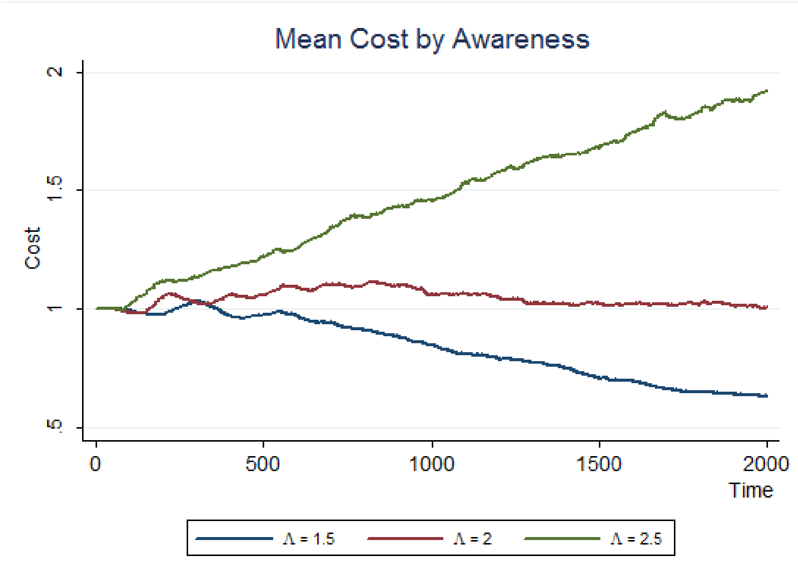
Figura 3.6: The Impact of Different Awareness Radius on HHI



A considerable difference is only observable when $\Lambda = 2.5$. It may suggest that before a certain threshold, Λ has an ambiguous effect on HHI, but after the threshold is surpassed consumer awareness begins to become negatively correlated with competition.

Now consider the impact of awareness on cost shown in the figure X below. In the models baseline scenario it can be seen that the cost initially rises, about $t = 200$ and then slowly falls from $t = 750$, until it stabilizes at initial value $c = 1$ from $t = 1250$ on. This suggests a predominance of product innovation at the beginning of the time frame which is slowly traded for process innovation at later stages of the market. This finding is consistent with Life Cycle Theory that theoretically predicts this pattern. Results are also comparable to Adner and Levinthal (2001), except that they consider a smaller time lapse which might explain why the initial parts of his baseline cost curve has a more distinguishable hump-shape.

Figura 3.7: The Impact of Different Awareness Radius on the Mean Cost of Firms



Awareness has clearly a powerful effect over the cost of firms and thus the pattern of product and process innovation. When awareness is bigger (smaller) than the baseline, market achieves saturation faster (slower) and thus R&D investments on product development grows (decreases) in proportion to process innovation driving the costs up (down).

Finally, figures 3.8 and 3.9 below show results for the impact of awareness on profit related variables: the mean mark-up and product innovation profitability of firms, this last one measured as the difference between the mean profit of firms selling the best-quality product at each point in t and the mean profit of the rest of the firms.

Figura 3.8: The Impact of Different Awareness Radius on Mean Mark-Up of Firms

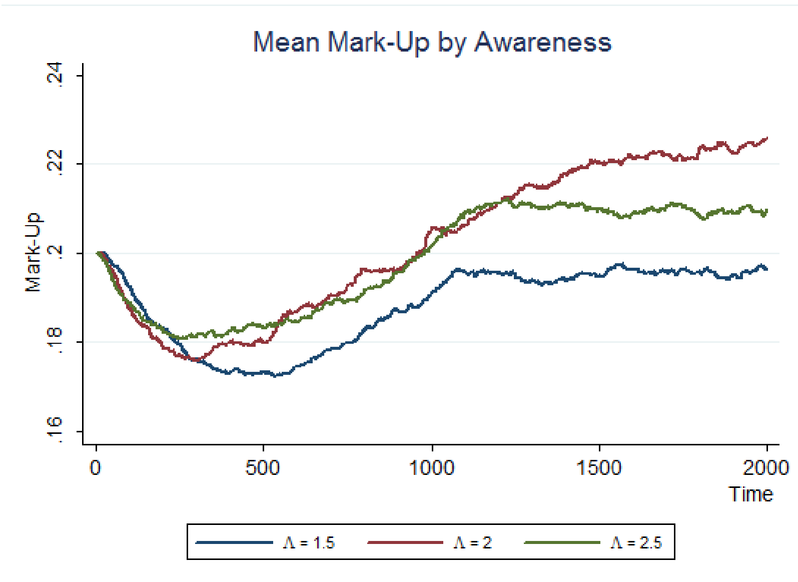
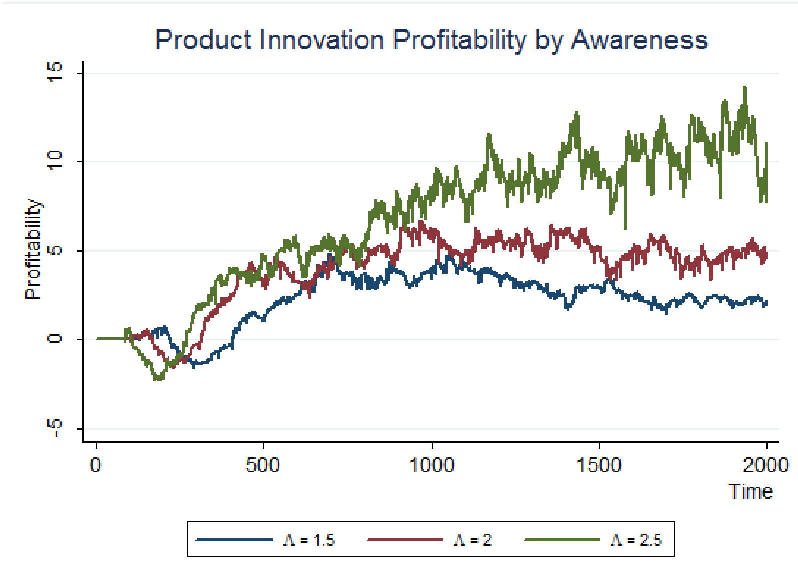


Figura 3.9: The Impact of Different Awareness Radius on Product Innovation Profitability



Product innovation profitability evolution behaves as expected. A larger awareness increases diffusion speed and thus raises profitability of new product. On the other hand, mean mark-up of firms seems to achieve its maximum with $\Lambda = 2$ which, at least in the spectrum of the economy modelled here, contradicts the claim that a greater market concentration directly implies higher mark-ups.

In the first stages of the market, the fast drop on concentration caused by the entry of the first non incumbent firms drives mark-ups down mainly because the incumbent has to adjust its prices to respond to entrants competitiveness. However, as mentioned before, fast technological advances makes more difficult for new firms to succeed, causing the entry/exit process to be more unstable and thus also mark-up adjustments. Additionally, the fact that the ratio product/process innovation is greater with larger awareness make the impacts of cost reductions smaller preventing large firms to have big cost advantages over other firms and thus making it more susceptible to price wars.

3.3.2 Varying Techies

The effects of varying the percentage of techies in the market are similar to those obtained changing awareness but with a few important peculiarities.

First, although it is observable that a higher techies percentage in the market also accelerates the speed of diffusion, it is not possible to infer that it raises maximum saturation achieved during each cycle. This is expected, since, unlike awareness shifts, differences in the number of techies does not affect the acceleration[31] of innovation diffusion, only its speed. Figures 3.10 and 3.11 bellow show saturation curves for the cases of 1 and 100 runs.

[31] Acceleration can be viewed as the second derivative of the life cycle (saturation) function.

Figura 3.10: The Impact of Different Percentages of Techies in the Population on Market Saturation (100 runs)

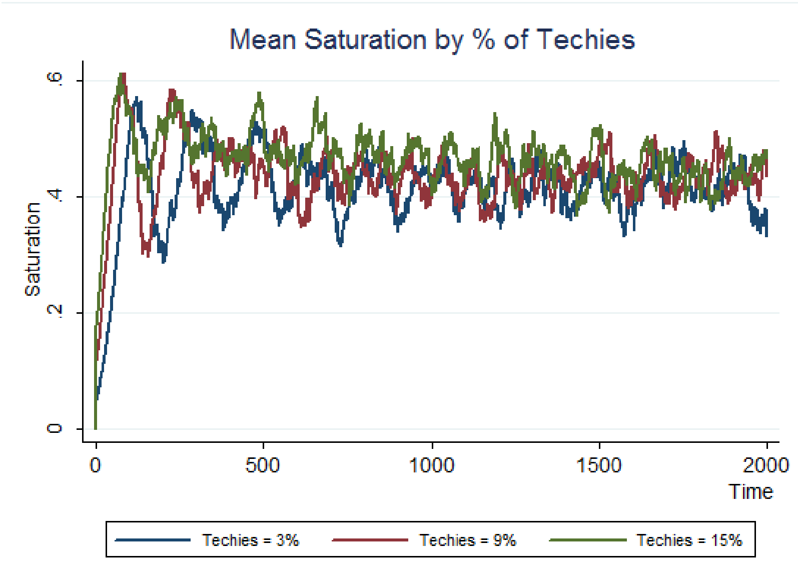
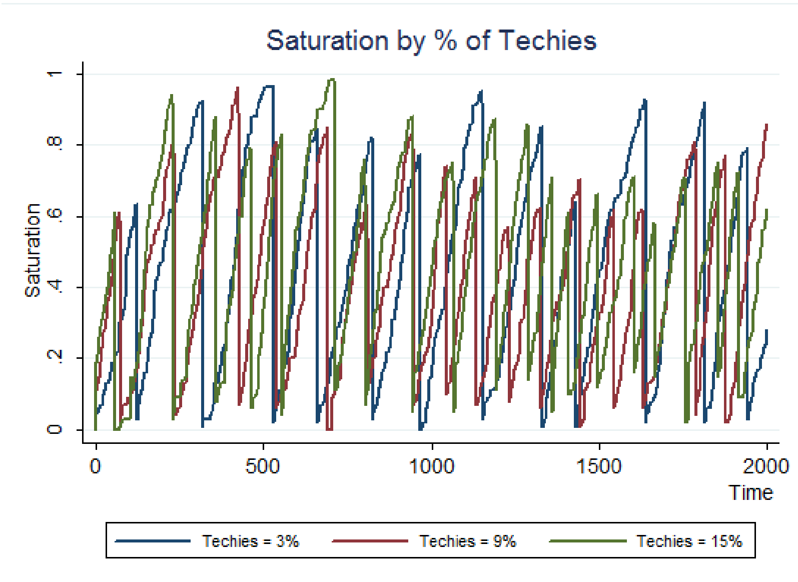
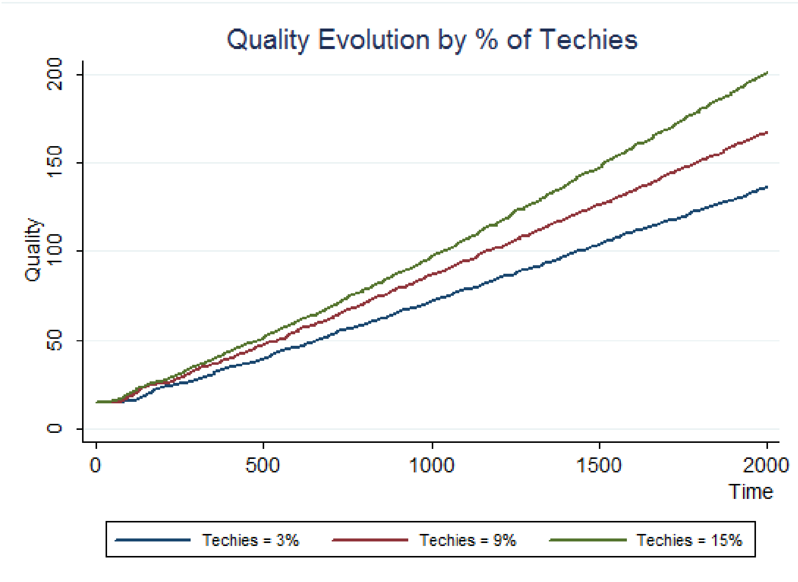


Figura 3.11: The Impact of Different Percentages of Techies in the Population on Market Saturation (1 run)



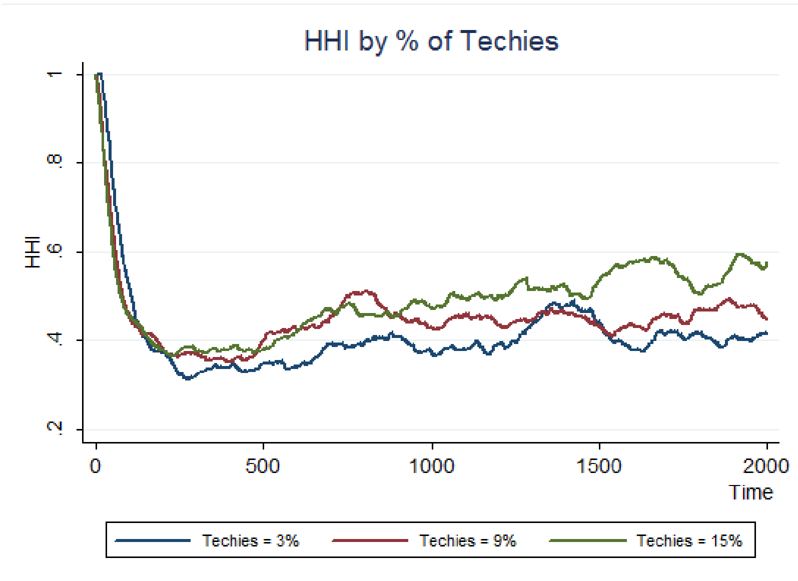
The evolution of product quality over time yielded the expected results. The higher the number of techies in the market, faster is the market saturation, leading firms to heavily invest on product innovation. It is interesting to note that, as can be seen in the figure 3.12 below, in the case in which techies correspond to 15% of consumers, results show that the curve can behave exponentially, indicating that the time between product innovations is getting shorter as time passes, albeit product quality is assumed in the model to present linear growth.

Figura 3.12: The Impact of Different Percentages of Techies in the Population on the Evolution of Product Quality



Results on market concentration also follow the same pattern as the awareness analysis, except this time the positive relationship between number of techies and HHI holds in the three scenarios analysed, in contrast to awareness effects in which only the maximum awareness level tested yielded significantly different results.

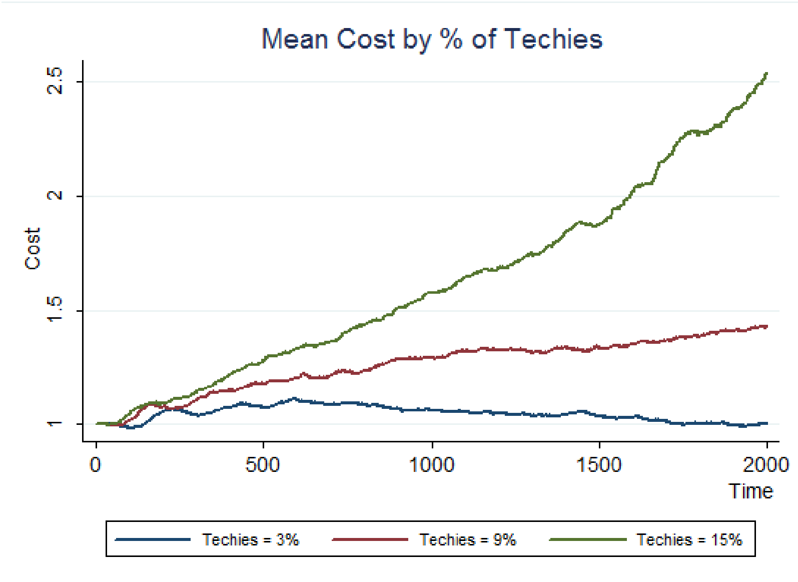
Figura 3.13: The Impact of Different Percentages of Techies in the Population on HHI



Raising the number of techies in the market also raises mean cost of firms, an indicative that firms are engaging more heavily on product innovation than process innovation.

Again, we can see an explosive tendency on the curve related to the maximum percentage of techies tested. Figure 3.14 below shows the results.

Figura 3.14: The Impact of Different Percentages of Techies in the Population on the Mean Cost of Firms



Finally, mean profits and profitability also rise with the increase in the percentage of techies. The once again present explosive tendency, this time of profits, may indicate that raising the percentage of techies above a given threshold may cause a certain degree of disequilibrium in the model. Nevertheless, it is hard to imagine a society where so many consumers are of “crazy-for-innovation” profile.

Figura 3.15: The Impact of Different Percentages of Techies in the Population on Mean Profits of Firms

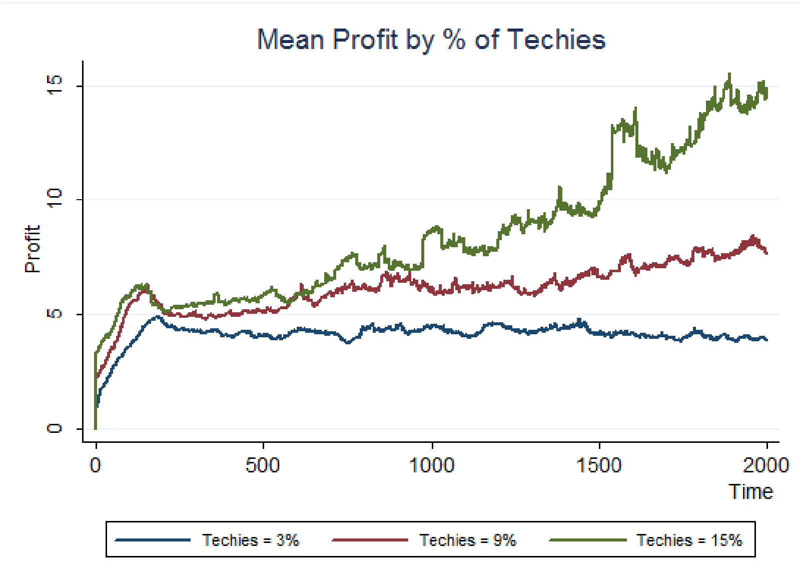
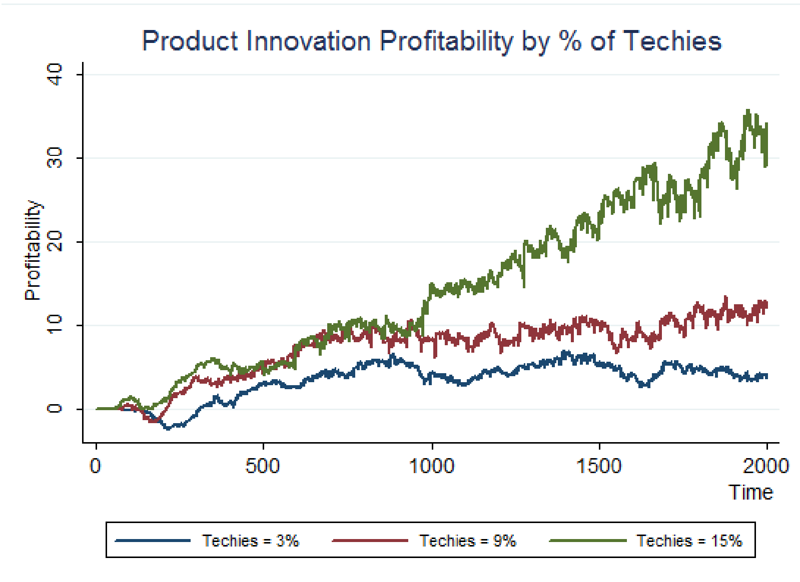


Figura 3.16: The Impact of Different Percentages of Techies in the Population on Product Innovation Profitability



3.4 Conclusion

In this chapter an agent-based model was presented with the goal to formalize and test the effects of bandwagon behaviour on the firms decision between process and product innovation. The chosen strategy was to test different values of consumer awareness

- which in this model are closely related to the degree of agents rationality - and percentage of techies in the market, a type of consumer that immediately buys new products at the exact time they are released.

Since there is still no empirical confirmation of the model, results should be viewed with precaution and considered purely theoretical. That being sad, results are very interesting and show that both awareness and percentage of techies have a positive effect on the ration between product and process innovation i.e. firms tend to value more product innovation over process innovation when rationality and percentage of techies increases. We also find that increasing awareness has a positive effect on the profitability and price charged by the firms, while the percentage of techies also affects mean profits of firms in the market and the Herfindahl Hirschman Index of market concentration.

There are several ways in which this model may be upgraded in future researches. A formal process of production decision could be incorporated, as well as labour market and consumer income inequality. The assumption of homogeneous awareness among consumers can be relaxed to capture the idea that some consumers are better informed than others.

Capítulo 4

Wealth Inequality and the Pattern of Innovation

In this section we present an agent-based model that seeks to capture the relationship between heterogeneous consumer behaviour in the face of unequal wealth endowments and firms decision process between investing in process or product innovation. We are motivated by the recent increase in global income inequality and the lack of consensus among economists about its causes and the evaluation of its consequences.

Regardless of causes and consequences, public managers and economists probably should not deliberately strive for a more unequal society. However, the discussion about growing or dividing the cake is still an important one specially for developing countries since the literature, so far, has failed to reach a consensus[1] on the macroeconomic impacts of income and wealth inequality.

While this lack of consensus might exist due to the simple fact that inequality may have no impact on the macroeconomic variables of common interest such as growth, employment, poverty, technological change, political outcomes and financial crisis, it might also be the case that economists have not fully understood exactly how inequality relates to these other subjects.

Motivated by the second option, we draw from the discussion presented by Moss et al. (2013) and assume that the mechanisms of transmission from inequality to macroeconomic variables are still mostly unknown to economic theory due to the lack of understanding on how different individuals behave according to their social status position in the relevant population. This clearly seems to be another problem of microeconomic foundations shortage while trying to tackle an economic problem.

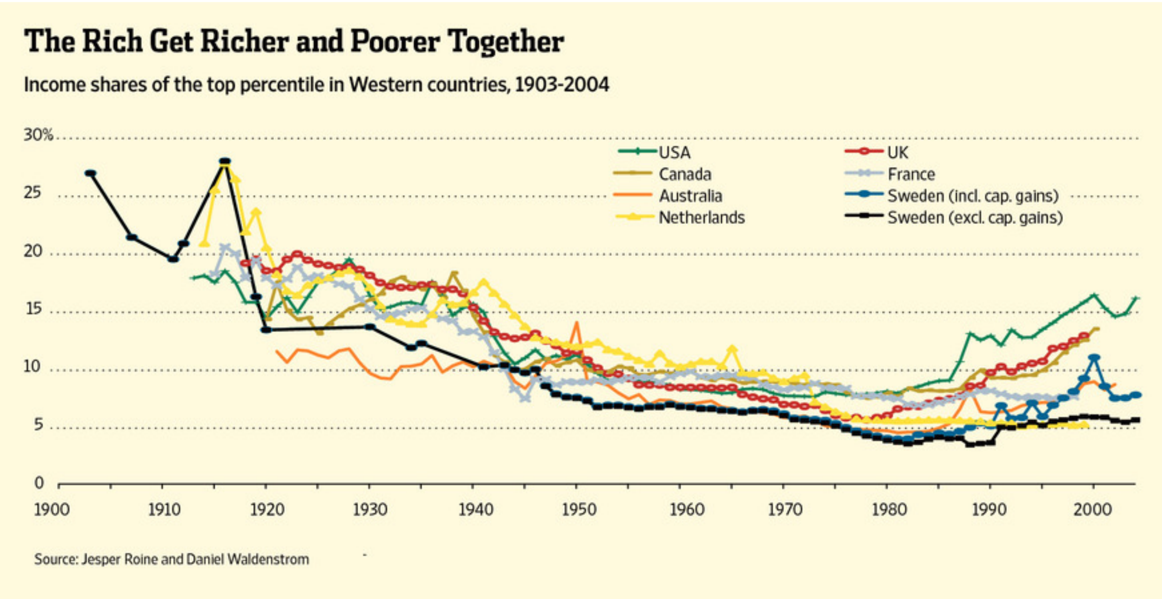
Results suggest that, despite the existence of an ambiguous theoretical effect of inequality over innovation, a more egalitarian society drives both product and process innovations up and leads to a more competitive market, with lower prices mark-ups and profit margins. Inequality always prevent product diversity and causes a higher exclusion of consumers from the demand for the latest best-quality product.

[1]See Moss et al. (2013) et al for a great review on the lack of consensus on inequality theory.

4.1 Introduction

The growth of world income inequality in the past 30 years (See figure 4.1 below), specially in the United States, but also in countries who supposedly had already reached a stable egalitarian society like Sweden, has renewed economists concern in the matter, recently feeding heated discussions about its causes and consequences, With one side claiming it to be a natural and beneficial process of capitalism while the other viewing the process as harmful and even the main cause for 2008 financial crisis.

Figura 4.1: World Income Inequality



French economist Thomas Piketty[2] is considered to be the sparkle generator. He argues that the recent increase in income inequality is caused by the fact that the rate of capital return is greater than the growth of GDP[3]specially on developed countries and the natural and only solution to this problem would be to raise taxes on the richest consumers.

Inequality is, however, a complex subject influenced by many other causes in addition to Piketty's. Amongst them, globalization of trade and finance is considered to have a positive effect on inequality by allowing multinational firms to shift labour and capital requirements spendings from home to countries where those inputs are cheaper. Decreasing power of labour market institutes and the slowing down of redistributive policies are also considered important facts for the recent rise in inequality. Finally, it is assumed that technological progress has ambiguous effects on inequality. The reason is that while the raise in profits and skill requirements tend to raise inequality, higher productivity arising from production process improvements have the opposite effect.

Regardless of causes and consequences, public managers and economists should never

[2]see Piketty (2013), Piketty (2006) and Piketty (2014).

[3]Gross Domestic Product.

deliberately strive for a more unequal society. However, the discussion about growing or dividing the cake is still an important one specially for developing countries since the literature, so far, has failed to reach a consensus[4] on the macroeconomic impacts of income and wealth inequality.

While this lack of consensus might exist due to the simple fact that inequality may have no impact on the macroeconomic variables of common interest such as growth, employment, poverty, technological change, political outcomes and financial crisis, it might also be the case that economists have not fully understood exactly how inequality relates to these other subjects.

Motivated by the second option, we draw from the discussion presented by Moss et al. (2013) and assume that the mechanisms of transmission from inequality to macroeconomic variables are still mostly unknown to economic theory due to the lack of understanding on how different individuals behave according to their social status position in the relevant population. This is clearly another problem of microeconomic foundations shortage while trying to tackle an economic problem. More specifically, we seek to analyse how the distribution of wealth shape the market pattern and thus the firm decision between process and product innovation.

Theoretical work on the subject has yielded an ambiguous relationship between income distribution and inequality. Authors like Zweimuller (2000), Iacopeta (2008), Foellmi (2005) and Foellmi et al. (2014) have suggested that, usually, a firm has a decision to make between investing in product innovation, to satisfy the needs of the rich agents, or process innovation, to make existing goods cheaper and conquer the demand of low income agents. This decision process, as already seen, is part of the Product Life Cycle Theory where given product starts at the top of the quality ladder and then gradually falls behind and end up being consumed only in underdeveloped markets by low income individuals.

The common conclusion of the aforementioned papers is that inequality fosters product innovation and equality drives process innovations up. This is because the larger the gap of wages and purchase power the costlier is for the firm to reduce prices so much to be able to sell to the bulk of consumers.

There are several examples of such phenomenon: cars, televisions, cellphones and basically all durable goods consumed in large scale nowadays started out incredibly expensive as a “luxury”to satisfy the needs of the rich and then after several process innovations can now be consumed basically by everyone, at least in developed countries. But still only a given portion of the population can immediately purchase the latest vintages of these durables.

Empirical analysis are usually focused on the other way around, trying to determine whether innovation increases or decreases income inequality. Aghion et al. (2015) and Banerjee (2014a) finds similar results that shows a positive relationship between innovation and top income inequality, while Jones and Kim (2015) achieves opposite conclusions.

The chapter is organized as follows: the next section presents a formal agent-based model in which consumers unequal wealth endowments and quality preferences influences

[4]See Moss et al. (2013) for a great review on the lack of consensus on inequality theory.

process and product innovation decision by firm. Results are presented in section 4.3, while the general conclusions can be found in section 4.4.

4.2 The Model

In this section another agent-based model featuring SPADA framework is presented. Although similar to the one in the previous chapter, there are several important differences to be described in this section[5]

The main difference between this and the previous model is that consumer heterogeneity arises from a uneven distribution of wealth other than from different bandwagon profiles. Consumers forming the set $\Omega = \{1, ..., N\}$ can still only buy one unit of one product at a time, are randomly spread across a bi-dimensional wrapped plain, defined by Γ, and have a fixed awareness radius of $\Lambda \subseteq \Gamma$, but this time bandwagon behaviour i.e. the propensity to be influenced by the set $\Theta_i(t) = \{j \mid (j, i) \in \Lambda_i\}$ of neighbours is the same for all consumers and defined by β. This time, however, we introduce a process of bandwagon accumulation and forgetting similar to equation 2.7 in which consumers have an amount of prolonged perception subject to memory limitations i.e. they are constantly forgetting older interactions. We call this process prolonged awareness, or E.

Additionally to bounded awareness, consumers also have no information about new products until successfully interacting with one of his neighbours. Even after the interaction, however, information about quality of the new product is not precise and is based only on a measure of perceived quality that decreases with time.

With regard to firms, there is again only one incumbent at time $t(0)$ that creates a new economic sector or market by inventing a completely new product. This time however, there is no initial marketing engagement by the incumbent and so consumers need necessarily to "drop by"' the firm to be able to cognize the new product. Firms can still freely try to enter or decide to exit the market assessing the other investment option available in the framework which yields the constant interest rate r. Thus at a given time $t \neq 0$ there will be a set $\Xi = \{1, ..., X\}$ of firms in the market producing a given number of products on-demand[6] that can be raised by introducing a new product through product innovation while product technology can be raised by process innovation thus reducing costs.

Costs can also be reduced by an exogenous process of learning-by-doing over time, while the quality of a product, although it remains unchangeable over time, falls to the eyes of consumers, who make purchasing decisions also based on this decreasing perceived quality

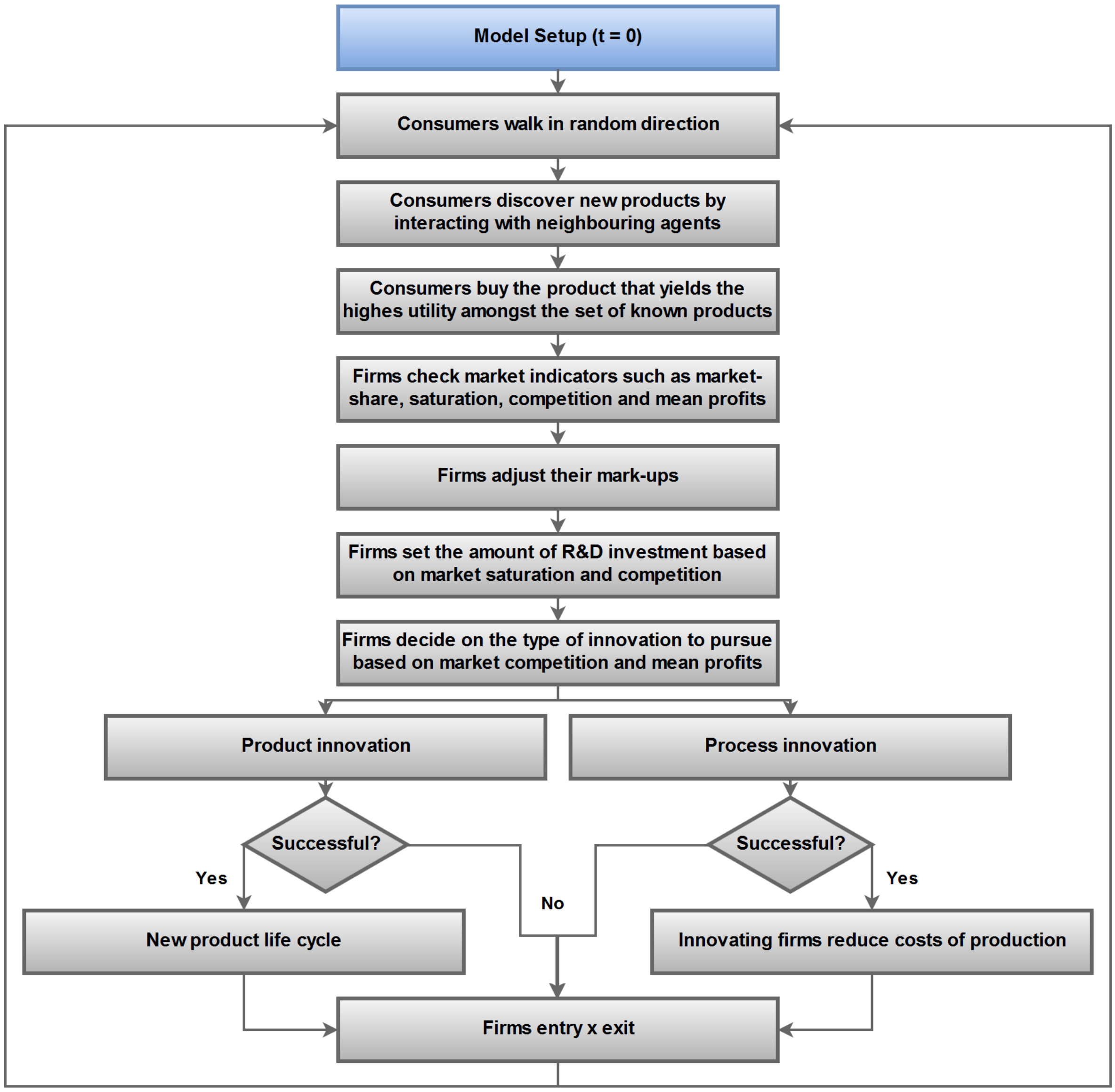
Since this model features wealth inequality, firms now make the decision between trying to perform product or process innovation differently from the previous model and use information about profits in the market instead of saturation and concentration. This is done to follow the literature on the subject which states that firms will keep investing in process innovations with the goal of lowering prices only until profits are

[5] We will refer to equations from the previous chapter to describe processes that are identical to those in that model.

[6] Or, in other words, by request of consumers.

rising with demand i.e. the effect of increasing sales on profit is higher than the negative effect of decreasing mark-ups and prices. The cyclical steps of this model simulation is similar to the one on the previous chapter and are described in the figure 4.2 below:

Figura 4.2: Cyclical Steps of The Simulation Model



A table (table C.1 containing a brief explanation of all variables described in the model as well as the simulation codes can be found in Appendix C and D at the end of the document.

4.2.1 Wealth Distribution and Utility

Wealth distribution of consumers is assumed to be exogenous and previously defined by a two-parameter log normal distribution with PDF[7] given by:

$$PDF = \frac{1}{w\sigma\sqrt{2\pi}} e^{-\frac{(\ln x - \eta)^2}{2\sigma^2}} \tag{4.1}$$

where w is the wealth and σ, η are the distribution parameters.

Thus, it is straightforward to note that the wealth of a given consumer will be given, according to log-normal distribution, as:

$$w = e^{\mu + \sigma\zeta} \tag{4.2}$$

where ζ is a standard normal variable[8]

The choice for a log-normal distribution[9] has to do with limitations of other types of distributions commonly used to capture income and wealth inequalities. Pareto distribution is the most famous among them and has a simple connection to Lorenz Curves and Gini coefficient, but the fact that it only has one parameter makes it inappropriate to test different income inequality scenarios since they would yield different wealth/income means on each simulation. Weibull distribution, also commonly used, has the two parameters needed to maintain the mean wealth constant with varying Gini indexes by setting one of the parameters as a function of the other. However, the resulting equation and the connection between Weibull distribution and the Gini index would be much more complicated to derive then in the case of log-normal distribution. The aforementioned equations will be shown in section 4.3.

After being assigned with a different wealth endowment, consumers are organized into one of three predefined possible social classes: poor, middle (middle class) and rich, with the percentage of consumers in each class being defined as 5% of riches, 35% of middles and 60% of poor. Each class values product perceived quality and price different in their utility functions, with the richer consumers preferring perceived quality over price and vice-versa.

The utility of a consumer is composed of two distinct terms. The first one takes into consideration only individual preferences and is given by a Cobb-Douglas function of perceived-quality and price[10], controlled by a parameter α which captures consumer preferences towards perceived-quality given their social class, with $0 < \alpha^p < \alpha^m < \alpha^r < 1$. The distance from a consumer to a product also affects utility, with closer goods being preferred over distance ones. The impact of distance is controlled by ξd and it is assumed that poor people places more value on distance than the other classes[11]

The second part of the utility captures bandwagon effects i.e. the utility gained by adopting the patterns of consumption of others. We assume that consumer bandwagon

[7] Probability Density Function.

[8] A normally distributed random variable with expected value 0 and variance 1.

[9] See Yurko (2006) for another example of log-normal distribution implementation to capture income inequalities.

[10] See Kalman (1968) for a review of the use of prices in utility functions.

[11] To capture the notion that poor people usually have less urban mobility in most cities.

behaviour follows a process similar to Robert Frank's[12] "expenditure cascade"' effect in which consumers feel the need to try to imitate consumption patterns of the class just above their own[13]. The utility obtained by consumer i from consuming product z is finally given by:

$$U_{i,z} = \nu_z^{\alpha} \left(\frac{1}{p_z}\right)^{1-\alpha} - \xi d_{i,z} + k_0 E_{i,z} \tag{4.3}$$

where ν_z and p_z are the perceived-quality and price of product z, $E_{i,z}$ is the prolonged awareness and $0 < k_0 < 1$ is a constant measuring the impact of bandwagon behaviour on utility. E is going to be described a little further in this section.

4.2.2 Dynamics of Perceived Quality and Price

The evolution of the perceived quality of a product ν_z brings an important discussion, directly connected to the behaviourist aspect of the utility function presented above, as well as some required simplifications to be implemented in the model. There is a vast literature[14] on the subject in which several arguments to consider perceived quality among consumers to be heterogeneous, such as brand reputation, personal past experience, price-as-quality situations and obsolescence with time. However, as far as the authors could research, there is no theoretical link between wealth inequality or social classes with different perceptions of quality. As much as it presents itself as a most interesting topic for future research, it is not the focus of this model and, since here the heterogeneity of demand only arises from different wealth endowments, a decision is made to consider perceived quality as homogeneous among consumers and monotonically decreasing with the age[15] of a product (τ_z)

This, however, does not exclude the opportunity to insert a degree of behaviour economics in our ν dynamics. Additionally to considering it decreasing with time, we follow the work done by the likes of Leavett (1954) and Putler (1992) and assume that perceived quality of a product is positively related to the products price. Thus, dynamics of perceived quality over time has two different components and is given by

$$\nu_z = q_z(\tau_z^{-o} + e^{k_1(p_z - \gamma)}) \tag{4.4}$$

where q_z and τ_z are the quality and the age of product z, o is an exogenous obsolescence rate of products, $k_1 > 0$ is a constant capturing the extent to which consumers are influenced by price to consider perceived quality and γ is the reference price of consumers in comparing perceived qualities by price.

Now lets take a look at the other component of the individual preferences part of utility function: prices. The cost evolution of a product over time also has two

[12]Franck et al. (2010) suggests that rapid income growth concentrated among top earners in recent decades has stimulated a cascade of additional expenditure by those with lower earnings.

[13]Poor consumers will try to imitate the middle class and the middle class will try to imitate rich people.

[14]See Ding et al. (2010) and Pamela (2007) for further information on perceived quality mechanics.

[15]The duration of the period since the product has been introduced by a given firm.

components: learning-by-doing[16] and the level of technology, the latter being affected by the introduction of successful process innovations. The process of learning-by-doing[17]is similar to the one impacting perceived quality and resembles Arrows classic form of the learning effect. Technology (A_z), on the other hand, depends on the rate of arrival of process innovations which in turn depends on the R&D investments on this type of innovation by the firm producing the given product. Dynamics of product costs are thus given by:

$$c_z(\tau) = c_z(0)[a_z^{-\iota}(t) - (A_z(I_x^{PC}, t) - 1)] \tag{4.5}$$

where $0 < \iota < 1$ is a parameter controlling the speed of learning-by-doing and $A_z(I_x^{PC})$ is the technology of product z at time t which depends on the amount of R&D investment on process innovation by firm x, producer of product z.

Firms are engaged in Bertrand competition and set their prices for each of their products based on a mark-up rule over costs. It is assumed that firms adjust their mark-up in response to increases or decreases in their products market-share. The difference from the previous model lies in the fact that now each product has its own market-share so the firm can have a better control of each one of them, balancing between higher mark-ups for the newest products sold with low competition for rich consumers and lower mark-ups for old saturated products with higher competition that pleases poor consumers. The price $p_{z,x}$ charged for product z of quality q by a firm x at time t is given by:

$$p_{z,x}(t, \tau) = \mu_{z,x}(t)c_{z,x}(t, \tau) \tag{4.6}$$

where $\mu_{z,x}(t)$ is the mark-up of product z of firm x at time t.

Note that the prices and costs doesn't vary only with time, but also with the age of each product. Mark-ups, however, are not dependant of product age. Prices are sticky in this model so firms wait a period T of time[18] before making the decision of altering the mark-ups of their products in order to assay if the tendency is persistent or seasonal.[19]. Mark-up adjustment process is given by:

$$\mu_{z,x}(t) = \begin{cases} \mu_{z,x}(t-1) + k_2\mu_{z,x}(t-1) & \text{if} \quad MS_{z,x}(t-T) < MS_{z,x}(t-T+1).... < MS_{z,x}(t) \\ \mu_{z,x}(t-1) - k_2\mu_{z,x}(t-1) & \text{if} \quad MS_{z,x}(t-T) > MS_{z,x}(t-T+1).... > MS_{z,x}(t) \end{cases} \tag{4.7}$$

where $0 < k_2 < 1$ is the constant amount of mark-up change when adjusted.

[16]See Arrow (1962) and Leiby et al. (1997) for more information about learning-by-doing theory.

[17]It is important to note that the concept of learning-by-doing here is distance itself from economies of scale, since costs drop with age and not with the size of demand

[18]Note that in the previous model τ was used to express this waiting period, but since this Greek letter is already being used to express product age it is substituted here for T.

[19]Due to managerial costs such as menu, customer negotiation and information gathering costs. See Zbaracki et al. (2003) for a detailed discussion.

4.2.3 Consumer Decision

With the information of prices and perceived qualities at hand, consumers can proceed to decide which one of the available products to buy. However, at time $t(0)$, they do not have acknowledgement about the new marker created by the incumbents invention and from this point are required to visit a firm to cognize new products or, in the case that other consumers have already acquired the product at time $t \neq 0$, to interact with them getting to know the products they are consuming.

The process of interaction between a given consumer i, other consumers and firms is very similar to the one presented in the previous model, except this time bandwagon behaviour β is homogeneous among consumers and after a successful interaction the purchase of a new product might not take place immediately since consumer i might not have enough wealth to buy the new product, or may not be interested to change products according to his utility value. Nevertheless, if a consumer interacts with other consumers or firms that possess different products from the ones he already know, he will have a chance to add these products to his list of products known.

We will start by addressing the case in which consumer i meets other consumer(s) in his awareness radius Λ_i. Consider by $\Psi_i(t) = \{1, ..., \infty\}$ the set of products known to consumer i at a given time t. At each point in time consumer i will choose only one consumer (if any) $j \in \Lambda_i$ to interact with. If consumer j owns a product not yet known to consumer i ($z_j \notin \Psi_i$) that product will be added to the list of products known by consumer i, Ψ with probability β. The process is detailed below:

$$z_j(t+1) \in \Psi_i(t+1) \quad \text{if} \quad z_j(t) \notin \Psi_i(t) \quad \text{and} \quad \beta > \epsilon \tag{4.8}$$

Consumer interaction also affects prolonged awareness. For simplicity, we can assume that E is a continuous process, other than discrete. Recall from the previous model that $|\Phi z(t) \cap \Theta i(t)|$ is the amount of agents in awareness radius Λ_i of consumer i that have already adopted a new technology. Thus, the process of accumulating and forgetting bandwagon experience can be viewed as:

$$E_i(t+1) = |\Phi z(t) \cap \Theta i(t)| - \delta E_i(t) \tag{4.9}$$

where $0 < \delta < 1$ is the forgetting rate (memory loss) of consumers.

At each point in time consumers choose the product yielding them the highest utility value from the set of products known $Z_i(t)$. Substituting equation 4.3 on equation 4.9 we have the decision process of consumers:

$$z_i = \arg\max_z \left\{ \nu_z^{\alpha} (\frac{1}{p_z})^{1-\alpha} - \xi d_{i,z} + k_0 E_{i,z} \mid z \in Z_i \right\} \tag{4.10}$$

4.2.4 Firms Procedures

R&D Investment Decision

The firms decision on the amount of R&D expenditures at each point in time perfectly resembles same the one in the previous model, with market saturation and competition playing a key role on the firms decision. A higher saturation increases the firms concern about the eventual total saturation of demand and stagnation of sales and thus its R&D expenditures. A higher market competition also raises R&D expenditures by increasing the intrinsic costs of failing to innovate and eventually fall behind in the technology ladders. The process is described in the equations below:

$$\theta_x = k_3\left(1 - e^{(-k_4 S_x)}\right) + k_5\left(1 - e^{(-k_6 \mathrm{HHI})}\right) \tag{4.11}$$

where θ_x is the chosen percentage of profits secured for R&D, $0 < k_{3,\ldots,6} < 1$ are constants, HHI is the Herfindahl Hirschman Index and S_x is the market saturation for the best-product of firm x. HHI and S_x are given by:

$$S_x = \frac{\sum_{i=1}^{N}[C_i \mid z_i = z_x]}{\sum_{i=1}^{N}[C_i \mid z_i \neq 0]} \tag{4.12}$$

$$\mathrm{HHI} = \sum_{x=1}^{X} ms_x^2 \tag{4.13}$$

where ms_x is the market-share of firm x. Thus the investment in R&D of firm x at time t is given by:

$$I_x^{R\&D} = \theta_x \Pi_x \tag{4.14}$$

with

$$\Pi_x = \sum_{z=1}^{Z} D_x(p_x - c_x) \tag{4.15}$$

where Π_x is the profit, D_x, p_x and c_x the demand, price and cost for each product of firm x.

Entry and Exit

The decision of a prospective firm to enter the market is identical to the previous model. At any point in time a prospective firm faces the decision of entering given the market situation. In order to make the decision, it is assumed that possible entrants observe the mean profit rate of currently operating firms, the saturation of the best-quality product and the concentration of the market. The higher the market profits and concentration and the lower the saturation, higher the probability to enter. Entrants will only be willing to produce the best-quality product in the market at time of possible entry. Additionally, the saturation of the chosen product cannot be higher than 50%[20]. Best-quality product saturation is given by:

[20] We assume a firm will never be willing to enter the market producing a good that is close to maximum saturation because the entrant won't have time to accumulate R&D investment for product and process innovation and will most likely fall behind on technology and product quality.

$$S_Z(t) = \frac{\sum_{i=1}^{N}[i \mid z_i(t) = Z(t)]}{N} \tag{4.16}$$

where z_i is the product being consumed by consumer i.

The mean profit rate of firms is:

$$\overline{\varpi} = \frac{\sum_{x=1}^{X} \frac{\sum_{z=1}^{Z} \varpi_{z,x}}{Z}}{X} \tag{4.17}$$

where $\varpi_{z,x} = \pi_{z,x}/I_x$ is the profit rate of product z of firm x.

And thus the decision of a given firm to enter the market is given by:

$$\text{Entry} = \begin{cases} \text{Yes} & \text{if} \quad S_Z < 0.5; \quad \overline{\varpi} > r; \quad \overline{\varpi} S_Z H > \epsilon \\ \text{No} & \text{Otherwise} \end{cases} \tag{4.18}$$

Exit however is a little different, since firms in this model can choose to shut-down a specific product line if the firm finds it to be unprofitable. Firms will decide to shut-down a product if its profit-rate over a range T of periods is smaller than the interest rate r, which means firms fight to keep their products alive as long as possible. Firms will still choose to exit the market according to equations X, but the process of shutting down a specific product is described below:

$$\text{Exit} = \begin{cases} \text{Yes} & \text{if} \quad \frac{\sum_{t=t-T}^{t} \varpi_{z,x}(t)}{T} < r \\ \text{No} & \text{Otherwise} \end{cases} \tag{4.19}$$

where $\varpi_{z,x}$ is the profit-rate obtained by firm x from selling product z.

Innovation type decision

A given firm x decide on what type of innovation to invest their R&D accumulated resources based solely on the weighted average of profits amongst firms producing the same product as firm x best-product. It means that firms will always be looking to the market performance of their best-quality product. If profits are on the rise, it is still worth it to invest in process innovation to raise demand, but if profits already start falling, firms are better off trying to introduce a new product in the market. This mechanism is suggested in several theoretical papers on the relationship between inequality and innovation, such as Foellmi (2005) and Foellmi et al. (2014). The weighted average profits a given firm x with best-quality product Z_x is concerned is given by:

$$\overline{\Pi} = \sum_{z=1}^{Z} \frac{\Pi_z D_z}{Z} \mid z = Z_x \tag{4.20}$$

In order to discover if $\overline{\Pi}$ is increasing or decreasing, given that it yields a set of discrete measurements, one can make use of the centred difference method, given by:

$$\dot{\overline{\Pi}}(t) = \frac{\overline{\Pi}(t) - \overline{\Pi}(t - \vartheta)}{\Delta t} \tag{4.21}$$

where ϑ corresponds to the size of the period analysed by the firm to make the decision.

The decision process can then be summarized as:

$$\text{Type} = \begin{cases} \text{Product} \Rightarrow I_x^{R\&D}(t) = I_x^{PD}(t) & \text{if} \quad \dot{\bar{\Pi}} < 0 \\ \text{Process} \Rightarrow I_x^{R\&D}(t) = I_x^{PC}(t) & \text{otherwise} \end{cases} \tag{4.22}$$

where PD means product innovation and PC process innovation. The probability of arrival of an innovation type is a linear function of the total amount of investment in one of them. It follows that:

$$\phi_x^{PD,PC} = k_8^{PD,PC} I_x^{PD,PC} \tag{4.23}$$

where $0 < k_8^{PD,PC} < 1$ are constants.

Effects of Successful Innovations

Successful innovations arrive with probability ϕ. A firm that successfully introduces a product innovation at time t immediately creates a new best-quality product with $Q_{Z,x}(t) = Q_{Z,x}(t-1) + Q_{Z,x}(t-1)\Delta Q$. If the firm is already at the quality frontier, the new product will also become the new global best-quality product. This new product arrives with a lower production technology than the previous best-quality product[21], given by $A_{Z,Q,x}(t) = A_{Z,Q,x}(t-1) - A_{Z,Q,x}(t-1)(\Delta A)^{PD}$ and it starts with no learning-by-doing experience and with $\nu_Q = Q_{Z,x}$. Finally, if the new product is indeed a new global best-product with no competition still, firm decides to set its mark-up to the maximum possible value, defined in the model as 0.3. Otherwise, the firm will set a mark-up identical to the mean of the mark-ups of products with same quality in the market.

A successful process innovation, on the other hand, increases the technology of production of every product the firm is producing at the time of innovation by $A_z(t) = A_z(t-1)(\Delta A^{PC})$. Process innovations, clearly, have a direct impact on products cost and it is the only effective way a firm can reduce a products price below a certain threshold, given the presence of diminishing returns to learning-by-doing in the model.

4.3 Results

In this section results for different values of wealth inequality given by the Gini index are presented. The values chosen for the Gini index are the real index values[22] of Sweden (0.25), United States(0.41) and Brazil(0.53), representing countries with completely disparate situations regarding inequality. 100 different simulation runs are performed for each of the scenarios, totalling 300 simulations over a $t = 2000$ time period.

There are a couple of simple procedures that have to be made before the simulation to ensure that our log-normal distribution yields the desired Gini values and, more

[21] Due to the firms lack of experience producing the new product.

[22] Source: OECD (Organization for Economic Cooperation and Development).

importantly, that the mean wealth of consumers remains constant through all Gini values tested and also through all simulations.

According to Yurko (2006) Gini index can be obtained by any log-normal CDF[23] by applying the following equation:

$$G = 1 - \frac{1}{\overline{w}} \int_0^{\infty} (1 - F(w))^2 dw \tag{4.24}$$

where G is the Gini index, $\overline{w}$ is the mean wealth of consumers and F(w) is the log-normal CDF.

To effectively keep the mean constant at all times, we take advantage in the fact that log-normal distributions have both a location (μ) and a scale (σ) parameter. This way, we can set the location parameter μ as a function of σ in order to keep the mean of the distribution constant. Using the expression for the mean of the log-normal distribution it is straightforward to assume:

$$\mu = \ln \overline{w} - \frac{\sigma^2}{2} \tag{4.25}$$

Throughout the simulations, it is thus assumed that the mean wealth of consumers is constant and takes the value $\overline{w} = 2$. Table 4.1 below brings the simulation values of the other constants of the model.

Tabela 4.1: Model Constants

Constant	Value	Constant	Value
Incumbents	5	Population	500
k_0	0.001	k_1	0.1
k_2	0.05	$k_{\{3,..,6\}}$	0.2
k_7^{PD}	0.01	k_7^{PC}	0.07
γ	0.1	α^r	0.8
r	0.01	α^m	0.5
(ΔQ)	0.2	α^p	0.2
$(\Delta A)^{PC}$	0.044	$(\Delta A)^{PD}$	0.2
o	0.10	ι	0.15

4.3.1 Market Indicators

We begin by analysing market indicators. Figures 4.3 and 4.4 below shows market saturation and HHI for each of the inequality measures. We can clearly see that the mean saturation between all the simulation runs is higher in the case of low inequality, confirming theoretical assumptions that new products diffuse faster in egalitarian markets due to the smaller gap between rich and poor. Competition is also much more favoured under low inequality than high inequality due to the higher maximum saturation levels on each PLC fostered by longer periods of increasing profits before decreasing that allows more firms to enter the market during each PLC.

[23] Cumulative Distribution Function

Figura 4.3: Effects of Wealth Inequality on Market Saturation

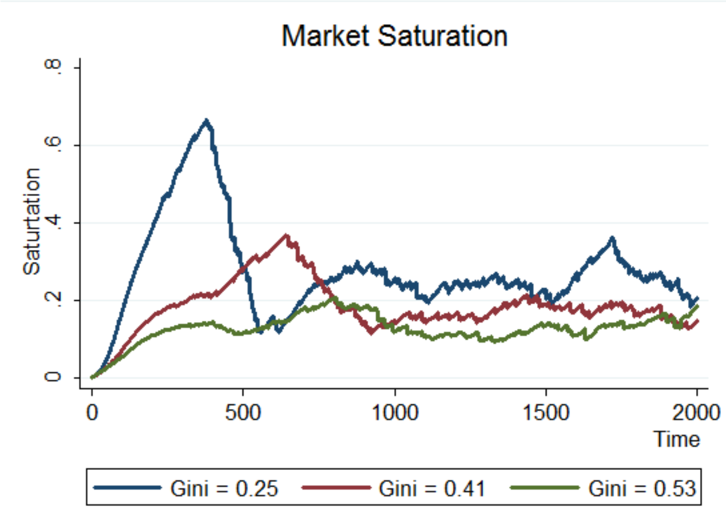
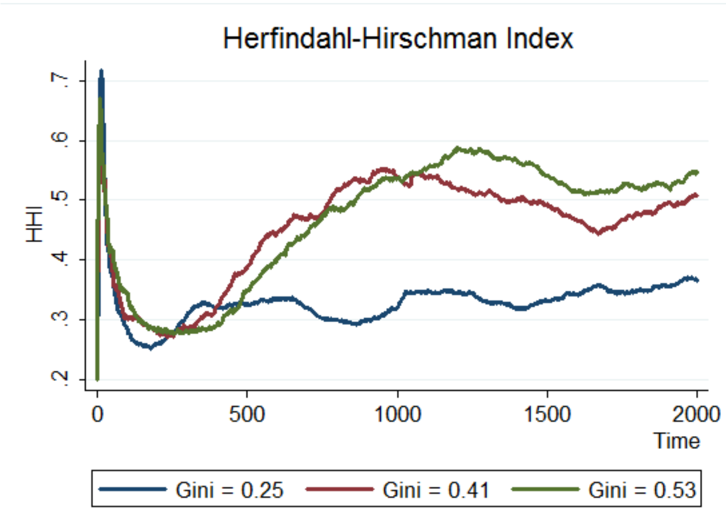


Figura 4.4: Effects of Wealth Inequality on Herfindahl-Hirschman Index



When inequality is high firms achieve their maximum profits from a product early in the product life cycle and thus quickly starts to invest in product innovation to raise the profits back up by introducing a new best-quality product to fulfil the needs of the rich. Even thou total profits will be lower under high inequality, mark-ups, prices and profit-margins will be higher due to the lack of competition. Note that process innovations are not the only way to reduce prices in the market, which can also be done by reducing mark-ups in face of severe competition what, according to the results of the model, is much less intense in high inequality cases.

This problem is only worsen in societies with a small middle class where the gaps between the rich and the poor makes heavy process innovation investments infeasible since there is almost no one to hold demand in a steady growth while the firm makes the necessary technological improvements to be able to sell to the masses. Figures 4.5, 4.6, 4.7 and 4.8 below brings the results for the mean prices, mark-ups, profits and profit-margins of the firms.

Figura 4.5: Effects of Wealth Inequality on the Mean Price Charged by Firms

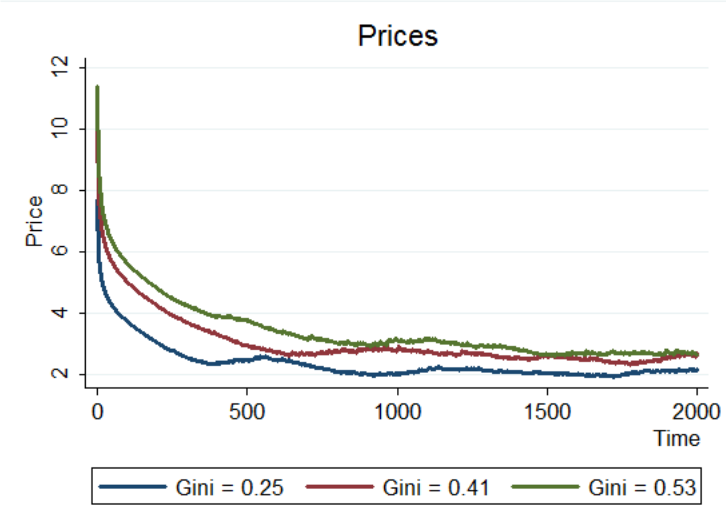


Figura 4.6: Effects of Wealth Inequality on the Mean Mark-up of Firms

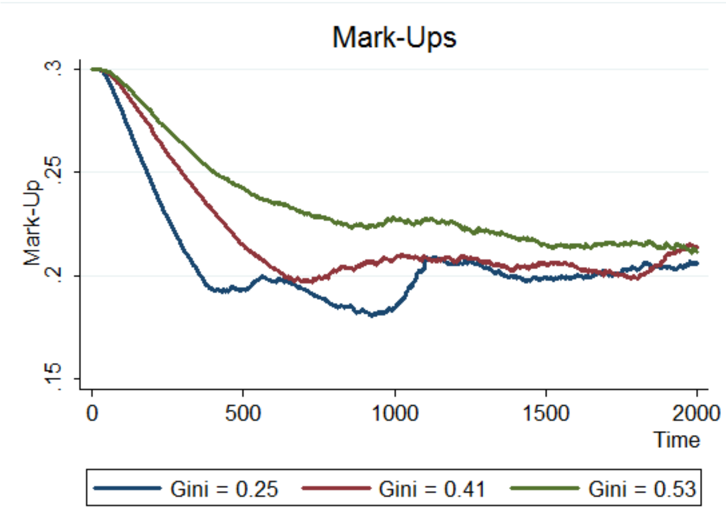


Figura 4.7: Effects of Wealth Inequality on the Mean Profit Obtained by Firms

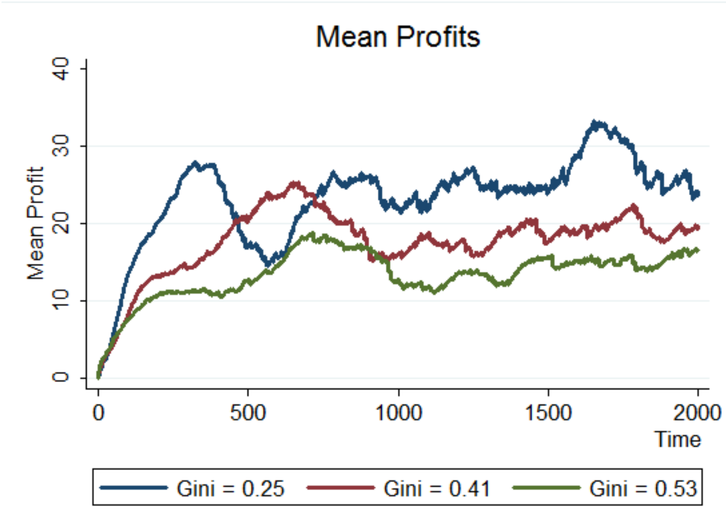
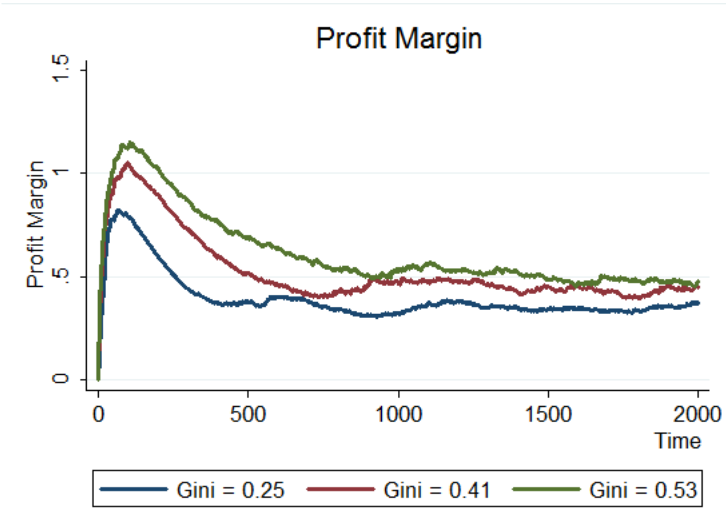


Figura 4.8: Effects of Wealth Inequality on the Mean Profit Margin of Firms



4.3.2 Innovation, Exclusion and Utility

Contrary to the theoretical assumptions of the aforementioned authors, results show that both product and process innovations are much more common under low wealth inequality situations. This means not only consumers will have cheaper products, but also a bigger diversity and access to better quality goods, as we can see below. This situation increases the options of consumption for all classes, considerably raising the mean utility amongst consumers and reducing the exclusion of a larger part of the population from the market of products with better quality.

Figura 4.9: Effects of Wealth Inequality on The Evolution of Product Quality

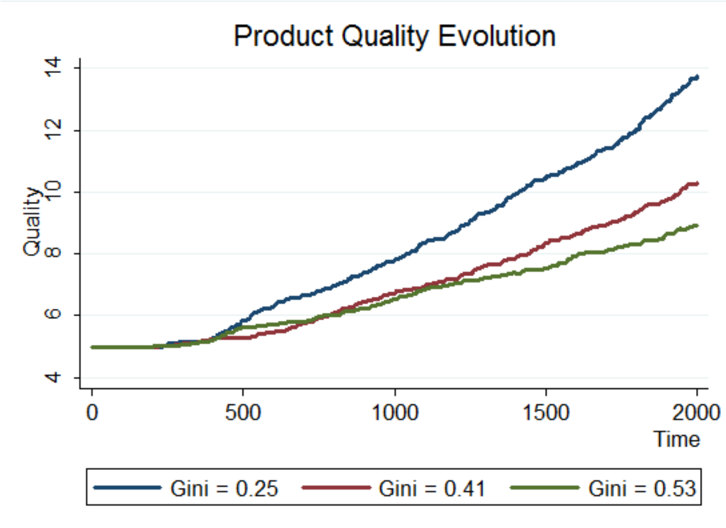


Figura 4.10: Effects of Wealth Inequality on Product Diversity

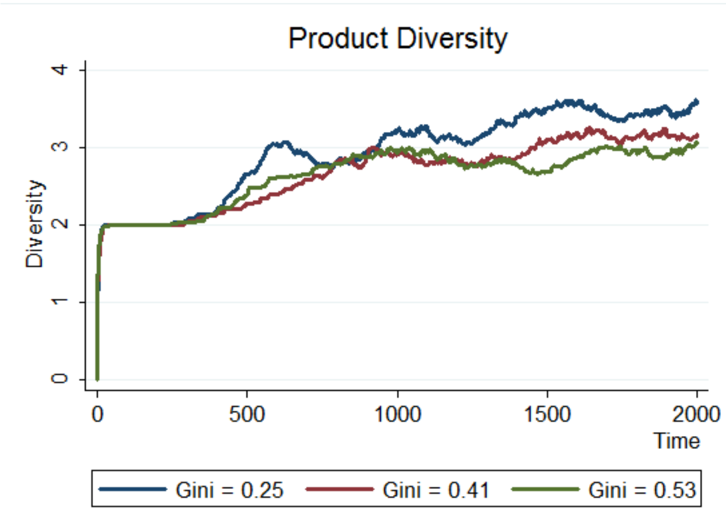


Figura 4.11: Effects of Wealth Inequality on Exclusion

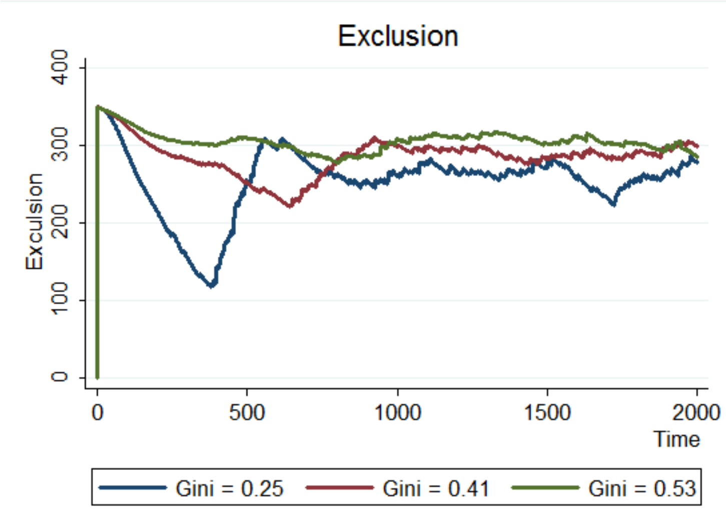
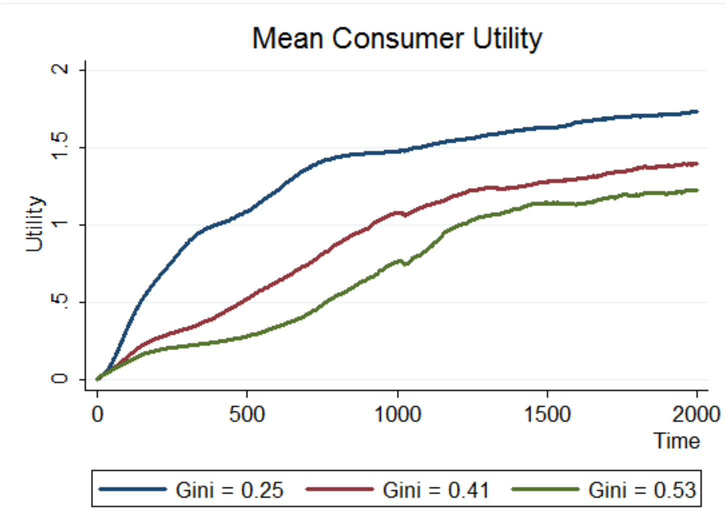


Figura 4.12: Effects of Inequality on Mean Consumer Utility



4.4 Discussion

In this chapter we have developed an agent-based model in which heterogeneity in wealth endowments shape consumers into different social classes that behave differently towards the adoption of new products. A degree of bandwagon behaviour, although homogeneous amongst consumers, is maintained in the form of bounded rationality using SPADA framework. Consumers have also a prolonged awareness that affects their utility decisions at each point in time by creating social pressures to follow the patterns of consumption of the classes above their own.

Results show that a more egalitarian society yields both product and process innovation increases. As a dynamic model, results should be viewed as a never-ending process of variables influencing one another. In this sense, it is advantageous to have an exogenously given wealth inequality so we are able to capture, and to impose, a beginning to this process and see the pure effects of inequality over the dynamics of the model. It is safe to assume that equality, right from the first product life cycle, became to shape a market with much more competition, leading firms to reduce their prices not only to raise their profits capturing a larger demand, but by having to survive the competition and reduce mark-ups. Even thou profit margins are lower with low inequality, firms are probably better off in this case, since total profits are still higher because of increased demand.

The greater product diversity and lower exclusion also contributes for the firms to get the best allocation of demand out of their products. A sign of this is that the mean consumer utility is considerably higher with low inequality. Even rich individuals are in a better situation[24]

Since there is no empirical confirmation of the model, we must be careful with our statements. Given the pessimistic conclusions of recent empirical works on the effects of innovation on inequality, one might argue that the increase in innovations caused by a more equal society could lead to rising inequality since entrepreneurs are making a larger amount of total profits. This could result in inequality/innovation cycles, an interesting subject for future research easily implemented in a model similar to this one, but with endogenous income, a labour market and, more importantly, a financial market to capture the idea that unequal societies remains unequal due to different propensities to save between rich and poor.

[24]Note that there is any kind of Veblen or snob effects in the model. Introducing them would probably yield a negative effect of equality on rich utility.

Capítulo 5

Conclusion

Throughout the course of history mankind has evolved and introduced a countless number of tangible and ethereal inventions and innovations that were key to define the path of development and behaviour of the present era. The savage did raise from under the tree and started to fulfil needs that, at each point in history, would be unimaginable in previous eras. Wants, arising out of survival necessity or pure lust, are tied together with technological change in a never-ending co-evolution process accelerated by the mesmerizing fact that human beings effectively learned how to create the most diverse types of wants in order to keep the wheels of evolution turning, whether its grease is called growth or development.

Despite the craving need to conform with the ones around us, be the standard enforced by law or a social convention necessary for one to be accepted in a group, each item on the set of human individuals, as the name suggests, behave differently and should not be view from afar as homogeneous, but with a magnifying glass, specially in economics. It is fairly common to hear people saying that we are approaching a robotic state in which everyone thinks and behaves exactly the same as we were all slaves of machinery like in Fritz Lang Metropolis. Notwithstanding the abysmal rotten intolerance and the lingering misery still present in our world we are probably doing much better than most generations that have preceded us. Freedom of speech and behaviour and the diversity of wants are certainly on the rise in developed and developing countries. It seems that scarcity, once economists biggest concern, is definitely being replaced by distribution.

The most recent take-off on the speed of agent interaction caused by the invention of the internet and globalization makes bandwagon behaviour even more important to understand the patterns of consumption in our society. Nowadays, products and ideas can be diffused or totally shoved in a matter of minutes because the edges that connect us have multiplied and every single node of us is entitled with a respect deserving opinion. Individual awareness and access to information has certainly increased, despite of the higher error functions caused by a huge part of this information being untrustworthy. Nevertheless, individuals of all classes have now easier access to new products and technologies and thus are inclined to try to pursue consumption patterns from individuals with higher wealth and income. It seems reasonable to suggest that economists and public managers should work to responsibly guarantee that the poor also have access to fulfilling their most diverse needs, specially basic ones, but also to follow a bandwagon of modernity and pleasure.

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Appendices

Appendix A

Chapter 3 Variables Description

Tabela A.1: Brief Description of Chapter 3 Variables

Variable	Description
Ω	Set of all consumers in the model
ω_i	A given consumer in the model
β	Stochastic bandwagon threshold of consumers
Γ	Bi-dimensional wrapped plain characterizing the economic space of the model
Λ	Awareness of consumers (constant in this model)
z	Denotes a product
Z	Denotes the best-quality product in the market
Φ	The set of all products in the market
q	Denotes the quality of a product
Q	Denotes the quality of the best-quality product in the market
x	A given firm in the model
ρ	Price paid by a consumer for a given product
Θ_i	Neighbouring set of a given consumer in the model
Φ_z	Subset of consumers who already adopted a given product at time t
χ_i	Product supplier of a given consumer
e	Total effort spent by a consumer to buy a given product
$d_{i,x}$	Distance of a consumer from a given firm
Ξ_i	Set of firms that can influence a given consumer
p	Denotes the price charged by a firm
F	Set of firms in the economy
r	Interest rate
S	Market or product saturation
HHI	Herfindahl-Hirschman Index
ms_x	Market-share of a given firm
π_x	Profit of a given firm
D_x	Demand of a given firm
c_x	Cost of a given firm
I	Investment

Tabela A.1: Brief Description of Chapter 3 Variables

Variable	Description
ϕ	Probability of arrival of an innovation
μ	Denotes Mark-up

Appendix B

Chapter 3 Code

```
breed [firms firm]
breed [consumers consumer]
breed [halos halo]
directed-link-breed [halos-links halo-link]
undirected-link-breed [deals-links deal-link]
globals
[
  hhi
  tprofit
  mprofit
  saturation
  dead-consumers
  best-quality
  quality-list
  inn_happen
  tchange
  test?
  innsat
  hight-profit
  lowt-profit
  diff-profit
]
firms-own
[
  profit
  profitr-h
  profit-rate
  demand
  quality
  cost
  fcost
  vcost
  market-share
  ms-history
  price
  age
  r&d-percent
  r&d-invest
  r&d-prod
  r&d-proc
  r&d-tot
  mark-up
  my-sat
  investment
  resources
  pinnova?
  change-ms?
]
```

```
consumers-own
[
  profile
  bandwagon
  client?
  vision
  price-paid
  quality-owned
  my-provider
  prob-change
  buy-distance
  effort
]
;;SETUP PROCEDURES;;
to setup
  ca
  setup-firms
  setup-consumers
  set-default-shape halos "thin␣circle"
  set best-quality 15
  set hhi 1
  set inn_happen 0
  set tchange 0
  set test? false
  let bt best-quality
  set quality-list (list (bt))
  set innsat 0
  reset-ticks
end
to setup-firms
  create-firms incumbents
  [
    setxy random-xcor random-ycor
    set shape "factory"
    set size 1.5
    set age 1
    set quality 15
    set color quality
    set demand 0
    set cost 1
    set mark-up 0.2
    set price (cost + (cost * mark-up)) ;{mark-up rule}
    set profit 0
    set profit-rate 0
    set market-share (1 / incumbents)
    let ms-now market-share
    set ms-history (list (ms-now))
    let profit-now profit-rate
    set profitr-h (list (profit-now))
    set my-sat 0
    set investment 100
    set resources investment
    set r&d-invest 0
    set r&d-tot 0
    set r&d-prod 0
    set r&d-proc 0
    set r&d-percent 0
    set pinnova? false
    set change-ms? false
  ]
end
to setup-consumers
  create-consumers newcomers
  [
    setxy random-xcor random-ycor
    set bandwagon 0.5
    set color white
    set shape "person"
```

```
    set size 1
    set vision awareness
    set client? false
    set my-provider nobody
    set price-paid 1000
    set quality-owned 5
    set prob-change 0
    set buy-distance 1000
    set effort (price-paid + buy-distance * distance-weight)
  ]
  let t ((count consumers) * (techies / newcomers))
  let v ((count consumers) * (visionaries / newcomers))
  let p ((count consumers) * (pragmatists / newcomers))
  let c ((count consumers) * (conservatives / newcomers))
  let s ((count consumers) - c - p - v - t)
  ask n-of t consumers with [bandwagon = 0.5]
  [
    set bandwagon 1
    set profile "qualityy"
    set my-provider firm 0
    set price-paid 1.2
    set quality-owned 15
    set color red
    create-deal-link-with firm 0
    ask my-deals-links
      [
        set color 2
      ]
    set client? true
    set buy-distance (distance-weight * distance firm 0)
    set effort (price-paid + buy-distance * distance-weight)
  ]
  ask n-of v consumers with [bandwagon = 0.5]
  [
    set bandwagon 0.8
    set profile "visionary"
  ]
  ask n-of p consumers with [bandwagon = 0.5]
  [
    set bandwagon 0.6
    set profile "pragmatist"
  ]
  ask n-of c consumers with [bandwagon = 0.5]
  [
    set bandwagon 0.4
    set profile "conservative"
  ]
  ask n-of s consumers with [bandwagon = 0.5]
  [
    set bandwagon 0.2
    set profile "skeptic"
  ]
end
to go
  move-consumers
  become-client
  set-best-quality
  change-quality-owned
  change-provider
  set-market-share
  change-prices
  check-demand
  check-profits
  set-saturation
  set-hhi
  set-r&dinvest
  process-innovate
  product-innovate
```

```
  check-change
  set-saturation
  entry
  exit
  high-low-profits
  ask consumers with [client? = true]
  [
    set buy-distance distance my-provider
    set effort (price-paid + buy-distance * distance-weight)
    set prob-change 0
  ]
  ask firms
  [
    let tquality quality
    set my-sat (count consumers with [quality-owned = tquality]) / (count consumers)
    set size 1.5 + (0.1 * count my-deals-links)
    set age age + 1
    let my-quality quality
    ifelse hhi > 0.5
    [
      set price (cost + (cost * mark-up))
    ]
    [
      set price ( (0.6 * (cost + (cost * mark-up))) + (0.4 * (mean [price] of firms with [quality =
          my-quality])))
      let c-price price
      if any? my-deals-links
        [
          ask my-deals-links
          [
            ask other-end
            [
              set price-paid c-price
            ]]]]]
  if ticks = 2000
  [
    stop
  ]
  if not any? firms
  [
    stop
  ]
  tick
end
;;CONSUMER PROCEDURES::
to move-consumers
  ask consumers
  [
    set heading random 360
    forward 1
  ]
end
to become-client
  ask consumers
  [
    foreach sort consumers
    [
      if client? = false
      [
        if any? firms in-radius awareness
        [
          let pot-quality sort-on [price] firms in-radius awareness
          let chosen-price [price] of first pot-quality
          let chosen-quality [quality] of first pot-quality
          let chosen-provider item 0 pot-quality
          let chosen-color [color] of first pot-quality
          if random-float 1 < bandwagon
          [
```

```
          set my-provider chosen-provider
          set price-paid chosen-price
          set quality-owned chosen-quality
          set color chosen-color
          set prob-change 0
          create-deal-link-with my-provider
          ask my-deals-links
          [
            set color 2
          ]
          set client? true
          set buy-distance (distance-weight * distance my-provider)
          set effort (price-paid + buy-distance)]
      ]]]]
end
to change-quality-owned
  ask consumers
    [
      let my-quality-owned quality-owned
      if any? consumers in-radius awareness with [quality-owned > my-quality-owned]
        [
          let count-neighbors count consumers in-radius awareness
          let cn-quality count consumers in-radius awareness with [quality-owned > my-quality-owned]
          let cn-percent (cn-quality / count-neighbors)
          set prob-change ( bandwagon * ((alpha * cn-quality) + ((1 - alpha) * cn-percent )))
          let cn-quality-list sort-on [price-paid] consumers in-radius awareness with [quality-owned >
              my-quality-owned]
          let new-quality [quality-owned] of first cn-quality-list
          let new-provider [my-provider] of first cn-quality-list
          let new-price-paid [price-paid] of first cn-quality-list
          if random-float 10 < prob-change
          [
            set price-paid new-price-paid
            set quality-owned new-quality
            set my-provider new-provider
            set prob-change 0
            set color quality-owned
            ask my-deals-links
              [
                die
              ]
            create-deal-link-with my-provider
            ask my-deals-links
              [
                set color 2
              ]
            set client? true
            set buy-distance (distance-weight * distance my-provider)
            set effort (price-paid + buy-distance)]]
      if any? firms in-radius awareness with [quality > my-quality-owned]
        [
          let pot-price sort [price] of firms in-radius awareness with [quality > my-quality-owned]
          let best-price min pot-price
          let pot-quality sort-on [price] firms in-radius awareness with [quality > my-quality-owned]
          let chosen-quality [quality] of first pot-quality
          let pot-provider item 0 pot-quality
          let chosen-color [color] of first pot-quality
          if random-float 1 < bandwagon
          [
            set color chosen-color
            set quality-owned chosen-quality
            set my-provider pot-provider
            set prob-change 0
            set price-paid best-price
            ask my-deals-links
              [
                die
              ]
```

```
          create-deal-link-with my-provider
          ask my-deals-links
            [
              set color 2
            ]
          set client? true
          set buy-distance (distance-weight * distance my-provider)
          set effort (price-paid + buy-distance)]
      ]]
end
to change-provider
  ask consumers
  [
    if client? = true
    [
      let my-quality-owned quality-owned
      if not any? consumers in-radius awareness with [quality-owned > my-quality-owned]
      [
        if any? consumers in-radius awareness with [quality-owned = my-quality-owned]
        [
          let count-neighbors count consumers in-radius awareness
          let cn-price count consumers in-radius awareness with [quality-owned = my-quality-owned]
          let cn-percent (cn-price / count-neighbors)
          set prob-change ( bandwagon * ((alpha * cn-price) + ((1 - alpha) * cn-percent )))
          let current-effort effort
          let pot-effort sort-on [effort] consumers in-radius awareness with [quality-owned =
              my-quality-owned]
          let p-effort [effort] of first pot-effort
          if p-effort < current-effort
          [
            let new-provider [my-provider] of first pot-effort
            let new-price-paid [price-paid] of first pot-effort
            if random-float 1 < prob-change
            [
              set my-provider new-provider
              set price-paid new-price-paid
              set prob-change 0
              ask my-deals-links
              [
                die
              ]
              create-deal-link-with my-provider
              ask my-deals-links
              [
                set color 2
              ]
              set client? true
              set buy-distance (distance-weight * distance my-provider)
              set effort (price-paid + buy-distance)
          ]]]]]]
end
to diffuse-quality
  ask consumers with [profile = "qualityy"]
    [
      if my-provider != nobody
      [
        let x-quality [quality] of my-provider
        let x-color [color] of my-provider
        let my-quality-owned quality-owned
        if x-quality > my-quality-owned
        [
          set quality-owned x-quality
          set color x-color
      ]]]
end
;;FIRMS PROCEDURES;;;
to set-market-share
  ask firms
```

```
  [
    if any? deals-links
    [
      let n-links count my-deals-links
      let total-pop count consumers with [client? = true]
      let ms-temp (n-links / total-pop)
      if market-share != ms-temp
      [
        set market-share ms-temp
        let ms-now market-share
        set ms-history fput ms-now ms-history
      ]]]
end
to change-prices
  ask firms
  [
    if length ms-history > 10
    [
      let ms-h ms-history
      let ms-0 item 0 ms-h
      let ms-1 item 1 ms-h
      let ms-2 item 2 ms-h
      let ms-3 item 3 ms-h
      let ms-4 item 4 ms-h
      if ms-0 < ms-1
        [
          if ms-1 < ms-2
          [
            if ms-2 < ms-3
            [
              set mark-up (mark-up - (mark-up * p-reaction))
              let my-quality quality
              set price ( (0.6 * (cost + (cost * mark-up))) + (0.4 * (mean [price] of firms with [quality
                   = my-quality]))) ; swedish paper % of firms that set prices by mark-up and by mean
              let c-price price
              set ms-history (list(ms-0))
              if any? my-deals-links
              [
                ask my-deals-links
                [
                  ask other-end
                  [
                    set price-paid c-price
                  ]]]]]]
      if ms-0 > ms-1
        [
          if ms-1 < ms-2
            [
              if ms-2 < ms-3
              [
                set mark-up (mark-up + (mark-up * p-reaction))
                set ms-history (list(ms-0))
                let c-price price
                if any? my-deals-links
                [
                  ask my-deals-links
                  [
                    ask other-end
                    [
                      set price-paid c-price]]]]]]]]
end
to check-demand
  ask firms
  [
    set demand count my-deals-links
  ]
end
to check-profits
```

```
  ask firms
  [ let demand-now count my-deals-links
    set profit (demand * (price - cost))
    set profit-rate (profit / investment)
    let profit-now profit-rate
    set profitr-h fput profit-now profitr-h
  ]
end
to entry
  if any? firms with [quality = best-quality]
  [
    ask one-of firms with [quality = best-quality]
    [
      let mean-profits mean [profit-rate] of firms with [ quality = best-quality]
      let mean-costs mean [cost] of firms with [ quality = best-quality]
      let mean-mark-up mean [mark-up] of firms with [ quality = best-quality]
      if mean-profits > (interest + op-cost)
      [
        if saturation < 0.5
        [
          if random-float 1 < (prob-entry * hhi)
          [
            hatch-firms 1
            [
              setxy random-xcor random-ycor
              set shape "factory"
              set size 1.5
              set age 1
              set quality best-quality
              set color best-quality
              set cost mean-costs
              set mark-up (mean-mark-up - (p-reaction * mean-mark-up))
              set price (cost + (cost * mark-up))
              set market-share (0)
              let ms-now market-share
              set ms-history (list (ms-now))
              set my-sat 0
              set investment 100
              set resources investment
              set pinnova? false
              set change-ms? false
              set r&d-proc 0
              set r&d-prod 0
            ]]
        ]]]]
end
to exit
  ask firms
  [
    if length profitr-h > 100
    [
      let list-profit sublist profitr-h 0 101
      let sum-profit sum list-profit
      let mn-profit (sum-profit / 100)
      if mn-profit < interest
      [
        if any? my-deals-links
        [
          ask my-deals-links
          [
            ask other-end
            [
              set client? false
              set color white
              set my-provider nobody
              set price-paid 100000
              set quality-owned 5
              set prob-change 0
```

```
          set buy-distance 1000
          set effort (price-paid + buy-distance * distance-weight)
        ]
        die
      ]]
      die
    ]]]
end
to set-R&dinvest
  ask firms
  [
    let sat my-sat
    let herf (1 - (sum [market-share * market-share] of firms))
    let new-rdsat (k4 * ( 1 - e ^ ( - k5 * sat))) ;;; Saviotti & Pyka (2012)
    let new-rdhhi (k4 * ( 1 - e ^ ( - k5 * herf)))
    set r&d-percent (new-rdsat + new-rdhhi)
    set r&d-invest (r&d-percent * profit)
    set profit profit - r&d-invest
    ifelse my-sat > (1 - hhi)
    [
      if my-sat > 0.5
      [
        set r&d-prod (r&d-prod + r&d-invest)
      ]]
    [
      set r&d-proc (r&d-proc + r&d-invest)
    ]
  ]
end
to product-innovate
  ask firms
  [
    let r&d-pd r&d-prod
    if my-sat > (1 - hhi)
    [
      if my-sat > 0.5
      [
        set pinnova? true
        if pinnova? = true
        [
          if random-float 10 < (k8 * r&d-pd)
          [
            set innsat saturation
            let old-quality quality
            set quality quality + 10
            let new-quality quality
            set color color + 10
            let col color
            set r&d-prod 0
            set cost (cost + (0.2 * cost))
            ask my-deals-links
            [
              ask other-end
              [
                if profile = "qualityy"
                [
                  set quality-owned new-quality
                  set color col
                ]
              ]
            ]
            set pinnova? false
          ]]]]
end
to process-innovate
  ask firms
  [
    let r&d-pc r&d-proc
```

```
    if my-sat <= (1 - hhi)
    [
      if random-float 10 < (k9 * r&d-pc)
      [
        set r&d-proc 0
        set cost (cost - (0.044 * cost))
      ]]]
end
;;GLOBAL PROCEDURES;;
to set-best-quality
  let bt sort-by > [quality] of firms
  let bt1 item 0 bt
  set quality-list fput bt1 quality-list
  set best-quality first bt
end
to check-change
  let total-pop count consumers
  let quality-pop count consumers with [quality-owned = (best-quality - 10)]
  set innsat (quality-pop / total-pop)
  set tchange 0
  let bt sort-by > [quality] of firms
  let btl length quality-list
  if btl > 1
  [
    let bt0 item 0 quality-list
    let bt1 item 1 quality-list
    if test? = false
    [
      if bt0 > bt1
      [
        set tchange 1
        set test? true
      ]]
    if bt0 <= bt1
    [
      set test? false]
  ]
end
to set-saturation
  let total-pop count consumers
  let quality-pop count consumers with [quality-owned = best-quality]
  set saturation (quality-pop / total-pop)
end
to set-hhi
  set hhi sum [market-share * market-share] of firms
end
to high-low-profits
  if any? firms with [quality != best-quality and age > 50]
  [
    if any? firms with [quality = best-quality and age > 50]
    [
      set hight-profit mean [profit] of firms with [quality = best-quality and age > 50]
      set lowt-profit mean [profit] of firms with [quality != best-quality and age > 50]
      set diff-profit (hight-profit - lowt-profit)
    ]]
end
to make-halo
  hatch-halos 1
  [ set size (2 * awareness)
    set color lput 64 extract-rgb color
    __set-line-thickness 0.5
    create-halo-link-from myself
    [ tie
      hide-link ] ]
end
;;Code by Einloft, P. ; Pereima, J.B.;;
```

Appendix C

Chapter 4 Variables Description

Tabela C.1: Brief Description of Chapter 4 Variables

Variable	Description
Ω	Set of all consumers in the model
β	Stochastic bandwagon threshold of consumers
Γ	Bi-dimensional wrapped plain characterizing the economic space of the model
Λ	Awareness of consumers (constant in this model)
E	Prolonged awareness procedure
w	Denotes wealth
η	Parameter of wealth PDF
σ	Parameter of wealth PDF
ζ	Standard normal variable
α	Captures consumer preferences given their social status
ν	Denotes perceived-quality
t	Denotes time
τ	Denotes the age of a product
γ	Reference price of consumers
A	Technology of a product
ι	Parameter controlling the speed of learning-by-doing
δ	Forgetting rate (memory loss) of consumers
Π	Denotes profit
ϑ	Size of the period analysed by the firm to make the innovation type decision
z	Denotes a product
Z	Denotes the best-quality product in the market
Φ	The set of all products in the market
q	Denotes the quality of a product
Q	Denotes the quality of the best-quality product in the market
x	A given firm in the model
Θ_i	Neighbouring set of a given consumer in the model
Φ_z	Subset of consumers who already adopted a given product at time t
$d_{i,x}$	Distance of a consumer from a given firm

Tabela C.1: Brief Description of Chapter 4 Variables

Variable	Description
p	Denotes the price charged by a firm
Ξ	Set of firms in the economy
r	Interest rate
S	Market or product saturation
HHI	Herfindahl-Hirschman Index
ms_x	Market-share of a given firm
π_x	Profit of a given firm
D_x	Demand of a given firm
c_x	Cost of a given firm
I	Investment
ϕ	Probability of arrival of an innovation

Appendix D

Chapter 4 code

```
extensions [numanal]
breed [firms firm]
breed [consumers consumer]
breed [products product]
directed-link-breed [fipro-links fp-link ]
undirected-link-breed [copro-links copro-link]
globals
[
  hhi
  saturation
  best-quality
  quality-list
  gini-index-reserve
  lorenz-points
  best-color
  pond-profits
  profit-list
  derivative-list
  profit-tendency
  diversity
  product-innovations
  process-innovations
  exclusion
]
turtles-own
[
  age
]
firms-own
[
  firm-profit
  firm-profitr-h
  firm-profit-rate
  firm-best-quality
  total-cost
  market-share
  ms-history
  r&d-percent
  r&d-invest
  r&d-prod
  r&d-proc
  r&d-tot
  my-sat
  investment
  pinnova?
  firm-profit-margin
  firm-quality
  firm-demand
```

```
]
consumers-own
[
  client?
  vision
  price-paid
  quality-owned
  wealth
  products-known
  my-product
  class
  my-utility
  perc-quality-owned
  bandwagon
  cdf
  erf
  prolongaware
  pa-list
]
products-own
[
  price
  quality
  cost
  base-cost
  profit
  profit-rate
  profitr-h
  profit-margin
  mark-up
  demand
  perceived-quality
  technology
  productivity
  prod-market-share
  prod-ms-history
  prod-invest
  poor-utility
  middle-utility
  rich-utility
  version-age
]
;;SETUP PROCEDURES
to setup
  ca
  setup-consumers
  set best-quality 5
  set quality-list []
  set hhi 1 / incumbents
  ask consumers
  [
    let ww sort-by < [wealth] of consumers
    let pt abs (0.6 * newcomers)
    let mt abs (0.95 * newcomers)
    let pt2 item pt ww
    let mt2 item mt ww
    if wealth < pt2
    [
      set class "poor"
      set shape "middles"
    ]
    if wealth >= pt2 and wealth < mt2
    [
      set class "middle"
      set shape "middles"
    ]
    if wealth >= mt2
    [
```

```
      set class "rich"
      set shape "riches"
    ]
  ]
  ask turtles
  [
    set age 1
  ]
  setup-firms
  set profit-list [0]
  set derivative-list [0]
  set profit-tendency 1
  set product-innovations 0
  set process-innovations 0
  reset-ticks
end
to setup-firms
  create-firms incumbents
  [
    setxy random-xcor random-ycor
    set shape "factory"
    set size 2
    set age 1
    set color 15
    set firm-profit 0
    set firm-profit-rate 0
    set market-share (1 / incumbents)
    let ms-now market-share
    set ms-history (list (ms-now))
    let profit-now firm-profit-rate
    set firm-profitr-h (list (profit-now))
    set my-sat 0
    set investment 100
    set r&d-invest 0
    set r&d-tot 0
    set r&d-prod 0
    set r&d-proc 0
    set r&d-percent 0
    set pinnova? false
    hatch-products 1
    [
      set shape "line half"
      set color 15
      set size 3
      set heading 0
      set base-cost min [wealth] of consumers with [class = "rich"]
      set cost base-cost
      set demand 0
      set mark-up 0.3
      set price (cost + (cost * mark-up))
      set quality 5
      set perceived-quality quality
      set technology 1
      set productivity 1
      set age 1
      set profit 0
      set profit-rate 0
      let prod-profit-now profit-rate
      set profitr-h (list (prod-profit-now))
      set profit-margin 0
      set prod-market-share (1 / incumbents)
      let p-ms-now prod-market-share
      set prod-ms-history (list (p-ms-now))
      set prod-invest 100
      set version-age 1
    ]
  ]
end
```

```
to setup-consumers
  create-consumers newcomers
  [
    setxy random-xcor random-ycor
    set color white
    set size 1
    let u random-float 1
    let a (1 + gini) / (2 * gini)
    let h maxwealth
    let l minwealth
    let b 5
    let k parameter-k-weibull
    let rn random-normal 0 1
    let mi (ln media - ((phi ^ 2) / 2))
    ;set wealth (mm / (random-float 1 ^ (1 / a)));
    ifelse use-pareto? = true
    [
      ;set wealth ( - (((u * h ^ a) - (u * l ^ a) - (h ^ a)) / ((h ^ a) * (l ^ a)))) ^ ( - 1 / a)
      let m Xm
      set wealth (xm / (u ^ (1 / a)))
    ]
    [
      ;set wealth (b * ( - ln u)^(1 / k))
      ;if wealth < 1
      ;[
      ; set wealth 1
      ;]
      set wealth (1 + e ^ (mi + (phi * rn)))
    ]
    set products-known []
    set my-utility 0
    set client? false
    set perc-quality-owned 0
    set price-paid 1000
    set quality-owned 0
    set my-product nobody
    set prolongaware 0
    set pa-list [0]
  ]
  update-lorenz-and-gini
end
to go
  move-consumers
  know-products
  buy
  update-perceived-quality
  update-cost
  update-price
  update-class-utility
  update-demand
  update-profit
  update-prod-market-share
  update-mark-up
  update-consumer-variables
  update-market-share
  set-firm-my-sat-and-quality
  set-firm-profits
  set-best-quality
  set-hhi
  set-saturation
  set-R&dinvest
  process-innovate
  product-innovate
  products-shutdown
  calculate-pond-profits
  check-diversity-exclusion
  entry
  exit
```

```
  ask turtles
  [
    set age age + 1
  ]
  ask products
  [
    set version-age version-age + 1
  ]

  if ticks >= 2000
  [
    stop
  ]
  tick
end
;;CONSUMER PROCEDURES;;
to move-consumers
  ask consumers
  [
    set heading random 360
    forward speed
  ]
end
to know-products
  ask consumers
  [
    let w wealth
    if any? products in-radius awareness with [ price <= w]
    [
      let pproduct one-of products in-radius awareness with [ price <= w]
      let p-known products-known
      if random-float 1 < k0
      [
        if member? pproduct p-known = false
        [
          set products-known lput pproduct products-known
        ]]]
    if any? consumers in-radius awareness with [client? = true and price-paid <= w]
    [
      let pconsumer one-of consumers in-radius awareness with [client? = true and price-paid <= w]
      let pconsprod [my-product] of pconsumer
      let pc-known products-known
      if random-float 1 < k1
      [
        if member? pconsprod pc-known = false
        [
          set products-known lput pconsprod products-known
        ]]]]
end
to buy
  ask consumers with [class = "poor"]
  [
    if length products-known > 0
    [
      let w wealth
      let pa prolongaware
      let palist pa-list
      let candidates products-known
      let paw-products sort-on [poorw-utility - (distance myself * poor-dist-weight) + pa] products with
           [member? self palist = true and price < w]
      let best-product2 sort-on [poorw-utility - (distance myself * poor-dist-weight)] products with
           [member? self candidates = true and price < w]
      foreach paw-products [ set best-product2 lput ? best-product2]
      let best-product reverse best-product2
      if length best-product > 0
      [
        let bp item 0 best-product
        let q [quality] of first best-product
```

```
      let pq [perceived-quality] of first best-product
      let p [price] of first best-product
      let u2 [poorw-utility - (distance myself * poor-dist-weight)] of first best-product
      if u2 > my-utility
      [
        ask my-copro-links
        [
          die
        ]
        create-copro-link-with bp
        [
          set color 3
          set hidden? true
        ]
        set my-utility u2
        set price-paid p
        set quality-owned q
        set perc-quality-owned pq
        set my-product bp
        set client? true
        set color [color] of my-product
      ]]]]
ask consumers with [class = "middle"]
[
  if length products-known > 0
  [
    let w wealth
    let pa prolongaware
    let palist pa-list
    let candidates products-known
    let paw-products sort-on [middlew-utility - (distance myself * others-dist-weight) + pa] products
         with [member? self palist = true and price < w]
    let best-product2 sort-on [middlew-utility - (distance myself * others-dist-weight)] products with
         [member? self candidates = true and price < w]
    foreach paw-products [ set best-product2 lput ? best-product2]
    let best-product reverse best-product2
    if length best-product > 0
    [
      let bp item 0 best-product
      let q [quality] of first best-product
      let pq [perceived-quality] of first best-product
      let p [price] of first best-product
      let u2 [middlew-utility - (distance myself * others-dist-weight)] of first best-product
      if u2 > my-utility
      [
        ask my-copro-links
        [
          die
        ]
        create-copro-link-with bp
        [
          set color 3
        ]
        set my-utility u2
        set price-paid p
        set quality-owned q
        set perc-quality-owned pq
        set my-product bp
        set client? true
        set color [color] of my-product
      ]]]]
ask consumers with [class = "rich"]
  [
    if length products-known > 0
    [
      let w wealth
      let candidates products-known
      let best-product2 sort-on [richw-utility - (distance myself * others-dist-weight)] products with
```

```
          [member? self candidates = true and price < w]
      let best-product reverse best-product2
      if length best-product > 0
      [
        let bp item 0 best-product
        let q [quality] of first best-product
        let pq [perceived-quality] of first best-product
        let p [price] of first best-product
        let u2 [richw-utility - (distance myself * others-dist-weight)] of first best-product
        if u2 > my-utility
        [
          ask my-copro-links
          [
            die
          ]
          create-copro-link-with bp
          [
            set color 3
          ]
          set my-utility u2
          set price-paid p
          set quality-owned q
          set perc-quality-owned pq
          set my-product bp
          set client? true
          set color [color] of my-product
        ]]]]
end

to update-consumer-variables
  ask products
  [
    let pq perceived-quality
    let q quality
    let p price
    let up poorw-utility
    let um middlew-utility
    let ur richw-utility
    ask my-copro-links
    [
      ask other-end
      [
        if class = "poor"
        [
          set price-paid p
          set quality-owned q
          let d (distance my-product) * poor-dist-weight
          set my-utility up - d
          set perc-quality-owned pq
        ]
        if class = "middle"
        [
          set price-paid p
          set quality-owned q
          let d (distance my-product) * others-dist-weight
          set my-utility um - d
          set perc-quality-owned pq
        ]
        if class = "rich"
        [
          set price-paid p
          set quality-owned q
          let d (distance my-product) * others-dist-weight
          set my-utility ur - d
          set perc-quality-owned pq
        ]
      ]]]
end
```

```
to prolong-awareness
  ask consumers with [class = "poor"]
  [
    let v perc-quality-owned
    if any? consumers in-radius awareness with [perc-quality-owned > v and class = "middle"]
    [
      let cv sort [my-product] of consumers in-radius awareness with [perc-quality-owned > v and class =
           "middle"]
      let cv2 length cv
      set prolongaware prolongaware + cv2 - (0.5 * prolongaware)
      let pa prolongaware
      let pl pa-list
      foreach cv [set pl lput ? pl]
      set pa-list pl
    ]]
  ask consumers with [class = "middle"]
  [
    let v perc-quality-owned
    if any? consumers in-radius awareness with [perc-quality-owned > v and class = "rich"]
    [
      let cv sort [my-product] of consumers in-radius awareness with [perc-quality-owned > v and class =
           "rich"]
      let cv2 length cv
      set prolongaware prolongaware + cv2 - (0.5 * prolongaware)
      let pa prolongaware
      let pl pa-list
      foreach cv [set pl lput ? pl]
      set pa-list pl
    ]]
end
;;PRODUCT PROCEDURES;;
to update-class-utility
  ask products
  [
    set poor-utility (perceived-quality ^ p-quality) + (price ^ (p-quality - 1))
    set middle-utility (perceived-quality ^ m-quality) + (price ^ (m-quality - 1))
    set rich-utility (perceived-quality ^ r-quality) + (price ^ (r-quality - 1))
  ]
end
to update-perceived-quality
  ask products
  [
    if 2 > (age ^ ( obs-rate))
    [
      set perceived-quality (quality * (age ^ ( - obs-rate) + (e ^ kk * (price - 1))))
    ]]
end
to update-cost
  ask products
  [
    if price > min [wealth] of consumers
    [
      let a version-age
      if ((a ^ ( - learning-by-doing)) > (technology - 1))
      [
        let cost-impact ((a ^ ( - learning-by-doing)) - (technology - 1))
        set productivity (1 / cost-impact)
        set cost (base-cost * (cost-impact))
      ]]]
end
to update-price
  ask products
  [
    set price (cost + (cost * mark-up))
  ]
end
to update-demand
  ask products
```

```
  [
    set demand count my-copro-links
  ]
end
to update-profit
  ask products
  [
    set profit (demand * (price - cost))
    set profit-rate (profit / prod-invest)
    let profit-now profit-rate
    set profitr-h fput profit-now profitr-h
    if demand > 0
    [
      set profit-margin (profit / demand)
    ]]
end
to update-prod-market-share
  ask products
  [
    let q quality
    let total-d count consumers with [quality-owned = q]
    if any? consumers with [quality-owned = q]
    [
      let ms-temp (demand / total-d)
      if prod-market-share != ms-temp
      [
        set prod-market-share ms-temp
        let prod-ms-now prod-market-share
        set prod-ms-history fput prod-ms-now prod-ms-history
      ]]]
end
to update-mark-up
  ask products
  [
    if length prod-ms-history > 10
    [
      let ms-h prod-ms-history
      let ms-0 item 0 ms-h
      let ms-1 item 1 ms-h
      let ms-2 item 2 ms-h
      let ms-3 item 3 ms-h
      let ms-4 item 4 ms-h
      if ms-0 < ms-1
        [
          if ms-1 < ms-2
          [
            if ms-2 < ms-3
            [
              set mark-up (mark-up - (mark-up * p-reaction))
              set price (cost + (cost * mark-up))
              let c-price price
              set prod-ms-history (list(ms-0))
              if any? my-copro-links
              [
                ask my-copro-links
                [
                  ask other-end
                  [
                    set price-paid c-price
                  ]]]]]]
      if ms-0 > ms-1
        [
          if ms-1 > ms-2
            [
              if ms-2 > ms-3
              [
                set mark-up (mark-up + (mark-up * p-reaction))
                set prod-ms-history (list(ms-0))
```

```
              set price (cost + (cost * mark-up))
              let c-price price
              if any? my-copro-links
              [
                ask my-copro-links
                [
                  ask other-end
                  [
                    set price-paid c-price
                  ]]]]]]]]
end
to products-shutdown
  ask products
  [
    if length profitr-h > 250
    [
      let list-profit sublist profitr-h 0 101
      let sum-profit sum list-profit
      let mn-profit (sum-profit / 100)
      if mn-profit < interest-rate
      [
        if any? my-copro-links
        [
          ask my-copro-links
          [
            ask other-end
            [
              set my-utility 0
              set client? false
              set perc-quality-owned 0
              set price-paid 1000
              set quality-owned 0
              set my-product nobody
            ]
            die
          ]]
        die
      ]]]
end
;;FIRMS PROCEDURES;;
to update-market-share
  ask firms
  [
    let my-demand sum [demand] of products-here
    if any? consumers with [client? = true]
    [
      let total-d count consumers with [client? = true]
      let ms-temp (my-demand / total-d)
      if market-share != ms-temp
      [
        set market-share ms-temp
        let ms-now market-share
        set ms-history fput ms-now ms-history
      ]]]
end
to set-firm-my-sat-and-quality
  ask firms
  [
    let xx sort-on [quality] products-here
    if length xx > 0
    [
      let x reverse xx

      let fb item 0 x
      let fb2 [quality] of fb
      let fbc [color] of fb
      set my-sat (count consumers with [quality-owned = fb2]) / (count consumers)
      set firm-quality fb2
```

```
      set color fbc
    ]]
end
to set-firm-profits
  ask firms
  [
    set firm-profit sum [profit] of products-here
    set investment sum [prod-invest] of products-here
    set firm-profit-rate (firm-profit / investment)
    let profit-now firm-profit-rate
    set firm-profitr-h fput profit-now firm-profitr-h
    set firm-demand sum [demand] of products-here
    if firm-demand > 0
    [
      set firm-profit-margin (firm-profit / firm-demand)
      set size 2 + (0.03 * firm-demand)
    ]]
end
to set-R&dinvest
  ask firms
  [
    let sat my-sat
    let herf (1 - (sum [market-share * market-share] of firms))
    let new-rdsat (k4 * ( 1 - e ^ ( - k5 * sat)))
    let new-rdhhi (k4 * ( 1 - e ^ ( - k5 * herf)))
    set r&d-percent (new-rdsat + new-rdhhi)
    set r&d-invest (r&d-percent * firm-profit)
    set firm-profit firm-profit - r&d-invest
    ifelse profit-tendency = 0
    [set r&d-prod (r&d-prod + r&d-invest)]
    [set r&d-proc (r&d-proc + r&d-invest)]
  ]
end
to product-innovate
  ask firms
  [
    let r&d-pd r&d-prod
    if profit-tendency = 0
      [
        set pinnova? true
        if pinnova? = true
        [
          if random-float 10 < (k8 * r&d-pd)
          [
            let qq firm-quality
            let cc color
            set color color + 10
            let col color
            set r&d-prod 0
            set product-innovations product-innovations + 1
            hatch-products 1
            [
              set color col
              set size 3
              set shape "line half"
              let head sort-by > [heading] of products-here
              let head2 item 0 head
              set heading head2 + 20
              set base-cost min [wealth] of consumers with [class = "rich"]
              set cost base-cost
              set demand 0
              set mark-up 0.3
              set price (cost + (cost * mark-up))
              set quality (qq + (qq * 0.2))
              let qqq quality
              set perceived-quality quality
              set technology 1
              set productivity 1
```

```
            set age 1
            set version-age [version-age] of one-of products with [quality = qqq]
            set profit 0
            set profit-rate 0
            let prod-profit-now profit-rate
            set profitr-h (list (prod-profit-now))
            set profit-margin 0
            set prod-market-share 1
            let p-ms-now prod-market-share
            set prod-ms-history (list (p-ms-now))
            set prod-invest 100
          ]
        ]
        set pinnova? false
      ]]]
end
to process-innovate
  ask firms
  [
    let r&d-pc r&d-proc
    let fq firm-quality
    if my-sat <= (1 - hhi)
    [
      if random-float 10 < (k9 * r&d-pc)
      [
        set r&d-proc 0
        set process-innovations process-innovations + 1
        ask products-here
        [
          if price > min [wealth] of consumers
          [
            set technology (technology + (technology * 0.01))
          ]]]]]
end
to entry
  if any? firms with [firm-quality = best-quality]
  [
    ask one-of firms with [firm-quality = best-quality]
    [
      if any? products with [quality = best-quality]
      [
        let mean-profits mean [profit-rate] of products with [quality = best-quality]
        let mean-mark-up mean [mark-up] of products with [ quality = best-quality]
        if mean-profits > (interest-rate)
        [
          if saturation < 0.5
          [
            if random-float 1 < (prob-entry * hhi)
            [
              hatch-firms 1
              [
                setxy random-xcor random-ycor
                set shape "factory"
                set size 2
                set age 1
                set color best-color
                set firm-profit 0
                set firm-profit-rate 0
                set market-share 0
                let ms-now market-share
                set ms-history (list (ms-now))
                let profit-now firm-profit-rate
                set firm-profitr-h (list (profit-now))
                set my-sat 0
                set investment 100
                set r&d-invest 0
                set r&d-tot 0
                set r&d-prod 0
```

```
          set r&d-proc 0
          set r&d-percent 0
          set pinnova? false
          let meancost mean [cost] of products with [quality = best-quality]
          let meanpq mean [perceived-quality] of products with [quality = best-quality]
          let meanva mean [version-age] of products with [quality = best-quality]
          let meanmkup mean [mark-up] of products with [quality = best-quality]
          let meantech mean [technology] of products with [quality = best-quality]
          hatch-products 1
          [
            set color best-color
            set size 3
            set shape "line half"
            set heading 0
            set base-cost min [wealth] of consumers with [class = "rich"]
            set quality best-quality
            let mq quality
            set version-age meanva
            set perceived-quality meanpq
            set technology meantech
            let a version-age
            let cost-impact ((a ^ ( - learning-by-doing)) - (technology - 1))
            set productivity (1 / cost-impact)
            set cost (base-cost * (cost-impact))
            set demand 0
            set mark-up meanmkup
            set price (cost + (cost * mark-up))
            set age 1
            set profit 0
            set profit-rate 0
            let prod-profit-now profit-rate
            set profitr-h (list (prod-profit-now))
            set profit-margin 0
            set prod-market-share 0
            let p-ms-now prod-market-share
            set prod-ms-history (list (p-ms-now))
            set prod-invest 100
          ]]]]]]]
end
to exit
  ask firms
  [
    if length firm-profitr-h > 200
    [
      let list-profit sublist firm-profitr-h 0 101
      let sum-profit sum list-profit
      let mn-profit (sum-profit / 100)
      if mn-profit < interest-rate
      [
        if any? products-here
        [
          ask products-here
          [
            ask my-copro-links
            [
              ask other-end
              [
                set my-utility 0
                set client? false
                set perc-quality-owned 0
                set price-paid 1000
                set quality-owned 0
                set my-product nobody
              ]
              die
            ]
            die
          ]]
```

```
      die
     ]]]
end
;;GLOBAL PROCEDURES;;
to set-best-quality
  let bq sort-by > [quality] of products
  let col sort-on [quality] products
  let bq1 first bq
  set quality-list fput bq1 quality-list
  set best-quality first bq
  set best-color [color] of last col
end
to set-saturation
  let total-pop count consumers
  let qual-pop count consumers with [quality-owned = best-quality]
  set saturation (qual-pop / total-pop)
end
to set-hhi
  set hhi sum [market-share * market-share] of firms
end
to calculate-pond-profits
  if saturation > 0
  [
    let numerator sum [profit * demand] of products with [quality = best-quality]
    let denominator sum [demand] of products with [quality = best-quality]
    if denominator > 0
    [
      set pond-profits numerator / denominator
      let pp pond-profits
      set profit-list fput pp profit-list
    ]]
  if length profit-list > 3
  [
    let x0 item 0 profit-list
    let x1 item 1 profit-list
    let derivative (x0 - x1)
    set derivative-list fput derivative derivative-list
  ]
  if length derivative-list > 100
  [
    let subd sublist derivative-list 1 101
    let reduc reduce + subd
    ifelse reduc > 0
    [set profit-tendency 1]
    [set profit-tendency 0]
  ]
end
to check-diversity-exclusion
  let col [color] of consumers
  let col2 remove-duplicates col
  set diversity length col2
  set exclusion count consumers with [quality-owned != best-quality]
end
;;REPORTERS;;
to-report poorw-utility
  report (perceived-quality ^ p-quality) * ((1 / price) ^ (1 - p-quality))
end
to-report middlew-utility
  report (perceived-quality ^ m-quality) * ((1 / price) ^ (1 - m-quality))
end
to-report richw-utility
  report (perceived-quality ^ r-quality) * ((1 / price) ^ (1 - r-quality))
end
;;LORENZ CURVE;;
to update-lorenz-and-gini
  let sorted-wealths sort [wealth] of consumers
  let total-wealth sum sorted-wealths
  let wealth-sum-so-far 0
```

```
  let index 0
  set gini-index-reserve 0
  set lorenz-points []
  repeat newcomers [
    set wealth-sum-so-far (wealth-sum-so-far + item index sorted-wealths)
    set lorenz-points lput ((wealth-sum-so-far / total-wealth) * 100) lorenz-points
    set index (index + 1)
    set gini-index-reserve
    gini-index-reserve +
    (index / newcomers) -
    (wealth-sum-so-far / total-wealth)
  ]
end
to-report lognormal-gini
  report (gini-index-reserve / count consumers) / 0.5
end
;; By Einloft, P. ; Pereima, J. B. ;;
```