Innovation and Imitation Strategies in the Age of the Upgrade*

– An Agent-Based Model –

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Abstract: This paper studies the dynamics of innovation and imitation in a market with rapidly shortening product life-cycles, driven by the acceleration of technological progress, but also new consumer preferences and behavior. Consumers became used to replace a durable good by a technologically advanced version far before it comes at age–to "upgrade" it. This new consumption paradigm challenges established approaches to firms' strategic choices. In particular, the choice of attempting to lead the field by developing innovative products, or to imitate competitor products to stay current without high R&D expenditure. We present an agent-based model of a durable consumer goods market, where producers innovate and imitate to compete on price, quality and preference fit. Consumers with heterogeneous preferences and diminishing utility derived from their current products are searching the market for upgrades. We evaluate the success of a range of archetypal innovation and innovation strategies in different competitive settings and market conditions. Further, we explore the interplay between consumer behavior, firms' strategic choices, product market competition, IPR regimes and technological change. We find that higher costs of imitation reduce competition and thereby the incentive for technological innovation. Pure imitation strategies are despite their cost advantages rarely successful, but with increasing imitation costs, leapfrogging strategies become attractive.

Keywords: Agent based simulation, innovation strategies, product life-cycle, innovation-imitation trade-off

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1. Introduction

In recent decades, traditional as well as emerging industries are confronted with an ongoing shortening of single product as well as whole product category life-cycles. This general change of industry dynamics is driven by the acceleration of technological progress, but also new consumer preferences and behavior (Guiltinan, 2009a). Consumers became used to replace a durable good by a new version far before it comes at age. Yet, they demand technical improvements in each successive generation: faster, lighter, more connected. Technological change co-evolves with consumer behavior in a mutually reinforcing manner, where market demands spur innovation efforts of the producers, but also these advances in new products triggering consumer upgrading behavior, enticing them into buying.[1] This phenomenon, coined as "the age of the upgrade" (Danaher et al., 2001; Huh and Kim, 2008; Topolsky, 2013), challenges established approaches to firms' strategic choices. In particular, the choice of attempting to lead the field by developing innovative products, or to imitate competitor products to stay current without high R&D expenditure. Traditionally, it has been argued that certain market and industry characteristics, such as the existence of a tight appropriability regime or the control over complementary assets, determine the extent to which firms are able to capture the profits of their innovation activities (Teece, 1986).

In this paper, we investigate whether existing frameworks and models for the strategic dynamics of innovation still apply in markets characterized by shortening product life-cycles, where consumers display preferences for continuous upgrades. Deploying an agent-based model (ABM), we analyze firm-level dynamics of innovation and imitation strategies in an emerging market. Further, we explore the interplay between consumer behavior, firms' strategic choices, product market competition, and technological change.

The ABM depicts the dynamics of a competitive market for a new product category over its life cycle. The simulated market combines the market features of representa-

[1] This phenomenon connects to the theory of "conspicuous consumption" firstly formulated by Veblen (1899), where novelty by and in itself creates its own demand.

tive agent models on step-by-step innovation (Aghion et al., 2001; Mukoyama, 2003; Slivko and Theilen, 2014)) with empirical findings on consumer behavior (Cecere et al., 2015; Venkitachalam et al., 2015) in the context of markets with upgrading behavior. Multiple producers compete on this durable consumer goods market by introducing products, where they apply innovation and imitation strategies based on the typologies by Valdani and Arbore (2007), Ulhøi (2012), and Pérez-Luño et al. (2007). They face market uncertainty, modeled by an *ex-ante* unknown distribution of consumer preferences, as well as technological uncertainty, represented by varying success of innovation efforts.

We evaluate the success of a range of archetypal innovation and innovation strategies in different competitive settings and market conditions. In addition, we test which conditions are most favorable for technological change.

The remainder of the paper is structured as follows. Section 2 reviews existing literature on theoretical frameworks as well as empirical findings on strategic choices regarding firm level innovation strategies, and later on provides a typology of innovation strategies. Section 3 explains the dynamics of the ABM model, where the results are discussed in section 4. Section 5 concludes, provides implications for theory and practice, and points towards future promising avenues of research.

2. Theory, Literature, and Conceptual Framework

The ABM developed in this paper draws on microeconomic models to set the market mechanisms, business strategy literature to set producer agent strategies, and empirical studies to inform consumer agent behavior. In the following paragraphs, this literature will be reviewed in order.

2.1. Market mechanisms

Representative agent models analyze the competitive dynamics of innovation and imitation in the context of sequential innovation (also called step-by-step innovation). A technology has multiple levels, and attempting to reach the next level requires mastery of the current one. Some models discuss process innovation, meaning a reduction in production cost for a fixed product, and others concern themselves with product innovation, meaning an increase in the technology level of a product.

An early model by Arrow (1962) demonstrated the “Arrow effect”, which is sometimes also called the “replacement effect”. In this model, there is always a single monopolist who has the lowest production costs. The current monopolist, or a newly entering firm, can engage in process innovation to reduce that cost. The monopolist has less incentive to engage in innovation than a newcomer, since his profit is only going to increase by the difference between his current profit and his profit at lower production cost, whereas the newcomer stands to gain the total monopoly profit after innovation.

Later models introduced a spillover effect, where a firm that does not innovate benefits from the innovation investment of its competitor. Aghion et al. (2001) and Slivko and Theilen (2014) present models with sequential process innovation in which firms in oligopolistic Cournot competition choose between innovating and relying on the spillover effect. In the model by Aghion et al. (2001), firms compete in Bertrand competition. The strength of the spillover is varied, and the authors conclude that the presence of strong imitation reduces firm incentives to innovate, but that weak imitation increases innovation effort in a neck-and-neck race. In the model by Slivko and Theilen (2014), firms compete in Cournot competition and three equilibria are found: either all firms innovate, some firms innovate and others imitate, or no firm innovates.

Mukoyama (2003) presents a modified version of the model by Aghion et al. (2001) with product innovation, and an explicit imitation strategy that brings the producer to the same production capabilities as the current leader. There are no spillovers. In order to innovate, a firm needs to be in the leadership position in the previous round. It is found that imitation can never be profitable without an external subsidy, because an imitator who copies the technology of a current leader will have to set his price equal to the marginal cost in the ensuing Bertrand price competition with the leader, which means zero profit. A current leader (monopolist) does not have an incentive to innovate until his product is imitated. This is the Arrow effect again, this time in a market with product instead of process innovation.

The imitation concept differs between models.Mukoyama (2003) assumes that imitation is a costly action and Aghion et al. (2001) and Slivko and Theilen (2014) take it as the absence of innovation effort, which yields a fraction of the innovator's benefit. In another model with sequential innovation by Bessen and Maskin (2009), imitation is a costly action that can be blocked by a patent. The Arrow effect is not present in this model, because innovation is a risky activity that, if successful, provides a fixed one-time profit to all firms that successfully innovate or imitate. If firms only interact once, patenting is necessary to incentivize innovation and to achieve the socially desired level of investment and innovation. With sequential innovation, patenting reduces overall welfare, because having legal imitation means that firms indirectly help each other by increasing the overall probability of creating the first innovation, which then enables potential profits from the successive innovation for all of them. Garcia (2005) presents an ABM where firms make strategic choices regarding an incremental (development) or innovative (research) product strategy, concluding that the sole focus on consumer preferences via incremental development without own innovation activities is not successful on a competitive market.

The ABM in this paper combines the features in the described models in a new way, relaxes assumptions, and brings in an additional dimension of consumer heterogeneity. As an ABM, the present model offers more flexibility than the equilibrium based models, and allows the analysis of more complex scenarios with more producers, which will be explained in the following section. The innovation concept in the ABM is sequential product innovation. However, unlike the model by Mukoyama (2003), a producer can also vary the amount of attempted technological improvement per innovation and does not have to be the current leader to innovate.

2.2. Consumer behavior and preferences

While the present model is mainly concerned with firm behavior and strategic decision making, a pivotal element is the explicit modeling of consumers' decision making process. Generally, demand–and the heterogeneity thereof– related properties of markets tend to be overlooked by models of firm behavior and industrial dynamics (Valente, 2012; Witt, 2001).

This demand side consumer decision making with respect to purchases of product upgrades, however, is to a large extent captured by literature on the diffusion of innovation, and the application of various types and classes of diffusion models. The main aim of such models is to explain the pattern, rate, and extent of how a novel product, process or another form of innovation gets adopted by a population.

In most diffusion models, the adaption decision is threshold based, which can be homogeneous among agents, heterogeneous, subject to "increasing returns in use" (e.g., Abrahamson and Rosenkopf, 1997; Arthur, 1994), or dependent on the agent's social network.

Also, percolation models (e.g., Cantono and Silverberg, 2009; Hohnisch et al., 2008; Silverberg and Verspagen, 2005) have been applied to describe and analyze the diffusion of innovation, where the adoption is usually dependent on simple decision rules based on cost minimization, or a heterogeneous consumer *reservation price* which can be interpreted as a subjective individual valuation.

A key focus of our paper and model is product upgrading, the dynamic wherein consumers are motivated to continually replace products with more advanced versions. Technology journalist Topolsky (2013) eloquently explains the upgrading behavior of consumers in what he calls the "age of the upgrade", which according to him materialized in the 1980s:

> "Prior to the 1980s, most consumer electronics were bought like appliances. They were major purchases. [...] Buying a television was like buying a refrigerator: you would own it until it no longer functioned and could no longer be serviced. But the almost-post-Cold War, globalised era of the

> '80s helped to change all that. More players got in the game. Manufacturing, now outsourced, became cheaper. Technology became a commodity, components shrunk, new economies boomed. Product release cycles quickened. [...] And everyone could have it if they wanted. This was not about buying for the ages – this was about buying for the now. [...] The consumer learned that the thing you already owned was going to be replaced, and the replacement was going to be awesome. A more awesome version of the same thing. And there would be something after that, too."

Fisher and Pry (1971) were the first to build a prediction model on the diffusion of a new generation of products using an S-shaped cumulative adoption function. They explain how consumers in diverse markets such as floor materials, energy sources and military equipment have upgraded from one technology to the other, and back up their arguments using data on US consumption from 1930 to 1967. This string of research continued into the 2000s and the pattern was also found in video game consoles and floppy disc drives (Danaher et al., 2001), personal computers (Huh and Kim, 2008) and smartphones (Venkitachalam et al., 2015). In the smartphone market, this dynamic is institutionalized through mobile carrier contracts that let consumers upgrade regularly and frequently.

Cecere et al. (2015) investigated the smartphone market too, and identified two dimensions of consumer preferences. The technology (vertical) level represents universally valued performance criteria of the product, such as a faster processor or longer battery life. The horizontal personal preference dimension presents the heterogeneous likes and dislikes of a consumer with respect to product attributes such as color, size, and trade-offs between technical features which distinguish them horizontally.

Based on these empirical findings on consumer behavior, consumer agents in the present model are constantly searching for upgrades to an improved version of their current product. If there is one, they check whether this product is sufficiently more advanced to warrant the purchase. In addition, consumers that have a product become unsatisfied with it over time, and long for an upgrade. This causes them to make upgrades that they would not have found to be worth their cost without this mechanism, reflecting the age of the upgrade mentality. This is modeled by heterogeneous consumer reservation prices for products, depending on the distance between the consumers' preferences and the products characteristics, as well as the consumers current product endowment. Consequently, the consumers' reservation price is equal to the utility gain of the new over the current product. Upgrading behavior is included in the model by diminishing utility over time that is provided by the current product endowment, decreasing the reservation price for new upgrades. We do not consider the origins of upgrading behavior, and potential endogeneity thereof. We further disregard the possibility of producer agents influencing the tendency to upgrade via "planned obsolescence" (Fishman et al., 1993; Guiltinan, 2009b, cf. e.g.,).

2.3. Strategy typology

The microeconomic models described in the first part of this theory section assumed oligopolistic producers that optimize by choosing between an innovation and imitation option. The producer agents of this paper each use one of four archetypal innovation and imitation strategies.

Based on the innovator and imitator strategies outlined in the typologies by Pérez-Luño et al. (2007), Valdani and Arbore (2007) and Ulhøi (2012), and the mechanics of our simulation model, we developed a synthesized typology of innovator and imitator strategies on the dimensions present in the ABM (figure 1).

Table 1: Strategies

	Innovation	Pure imitation	Lateral imitation	Leapfrogging
Technology strategy	Lead	Imitate most popular product	Imitate most advanced product	Imitate most popular product, then improve it
Preference strategy	Market research	Imitate most popular product	Market research	Imitate most popular product

We differentiate between innovation strategies, which take departure from the company's current knowledge, and imitator strategies, which begin with a competitor's product. In that respect, we only consider products that are completely genuine as innovation, while products which are a modification or improvement of a competitor are considered to be imitations. This perspective is in line with Valdani and Arbore (2007) and different from the view of Pérez-Luño et al. (2007), who would classify a move as an innovation as long as the outcome product is different from existing products.

We define one innovation strategy and three imitation strategies. The innovation strategy is completely self-reliant. All market research and R&D is conducted independently, and the producer splits their effort between horizontal and vertical development. There are three imitation strategies. The pure imitation strategy means to create exact copies of competitor products. This is the equivalent of the strict imitator type in Pérez-Luño et al. (2007), clone products in (Valdani and Arbore, 2007) and the replica and mimicry strategies in (Ulhøi, 2012). Next, the lateral imitation strategy means to imitate the technology of an existing product and to make changes that make the product conform to the tastes of another customer segment. This strategy is similar to the explorer type in the typology by Pérez-Luño et al. (2007). Lastly, the leapfrogging strategy means to create a product that is closely based on an existing one, with the same design choices and geared towards the same customer segment, but that offers more advanced technology. It looks the same as the original, is marketed in the same way, and is a direct improvement over it. This strategy type is called incremental innovators by Pérez-Luño et al. (2007), parasite imitation by Valdani and Arbore (2007) typology and an emulation strategy by Ulhøi (2012).

3. Model Description

The purpose of this modeling exercise is to explore the dynamics of competition between a set of archetypal innovation and imitation strategy on a market with upgrading characteristics, both in terms of individual firm profits and the rate of technological change on industry level. ABM approaches are particularly well suited for modeling such market dynamics, since they take the complexity and substantive uncertainty associated with a firm's maximization problem into account, and can be modeled as rule-based strategies rather than derived as the solution of a tractable well-posed optimization problem (Dawid, 2006). The present model contains heterogeneity on consumer side in terms of preferences, and on producer side in terms of strategic decision rules.

The model is based on the following assumptions:

1. Agents are utilitarian: Decisions are made solely to maximize the agent's individual utility function.
2. Agents are myopic: No learning takes places, only short-term utility gains influence decision making. Historical knowledge vanishes. past and future utility is disregarded.
3. Constant preferences of consumer agents.
4. Consumer agents utility derived from current product endowment diminishes over time.
5. Consumer agents are subject to perfect information on available products, and their characteristics.
6. Producer agents are subject to imperfect information on consumer preferences.
7. Producer agents compete in an oligopolistic market.
8. Marginal production costs of products are zero.

3.1. Initial setup

To start, 100 consumers and a number of producer agents according to the parameter n_{type} are created. They are placed on a 20x20 grid, where each intersection represents one possible product configuration. The vertical dimension is the technology level of the product, and the horizontal dimension the preference fit. We assume that a set of products offered in a market can be represented as vectors over a set of characteristics (cf. e.g., Lancaster, 1966; Saviotti and Metcalfe, 1984), which we collapse to two dimensions. Each product matches certain consumer preferences, and has a measure of technological sophistication. The product space grid wraps horizontally, which means that the environment of the simulation is actually the surface a vertical cylinder, reflecting a continuum of consumer preferences. Product configurations are horizontally ordered on the grid according to similarity, meaning the further their distance, the more this particular product configuration appeals to different consumer preferences, and likewise, the higher the distance of the knowledge base necessary for producers to develop such a product.

Producers are initially placed vertically at the lowest technology level and horizontally at random positions on the preference axis. Their location represents their current knowledge base. When the new product industry emerges, they have only the minimum knowledge required to make a basic product. Over time, they move up in the technology level as they invest in R&D, or imitate other producers. Consumers are placed randomly on the preference axis, leading to an uneven preference distribution, where some product configurations appeal to more consumers than others. The distribution of consumers is *ex-ante* unknown to the producers, and has to be discovered successively via market research, resembling the search for high performing products on a technology "fitness landscape" (eg. Fleming and Sorenson, 2001; Geisendorf, 2009; Hain and Mas Tur, 2016; Posen et al., 2011). The initial configuration of further parameters, which are to be introduced yet, can be found in table 3.

3.2. Schedule

In each round, all producer and consumer agents take an action. The schedule is:

1. For consumers already in possession of a product: Utility derived from their current product decreases.

2. Producers sequentially (if part of their strategy) conduct market research, R&D, and create products. The order of producers is random in each round.

3. All consumers scan the market for new products, and buy one if it is a worthwhile upgrade for them.

The schedule is repeated until a producer places a product at the highest technology level. This move is interpreted as the end of the product category life-cycle, when many incremental generations of products have run their course, the current technological trajectories offers no possibilities for further improvement, and is finally overturned by new one which follows a different paradigm. If the highest technology level can never be reached, either because the producers capable of increasing the technology level have gone bankrupt, the simulation ends.

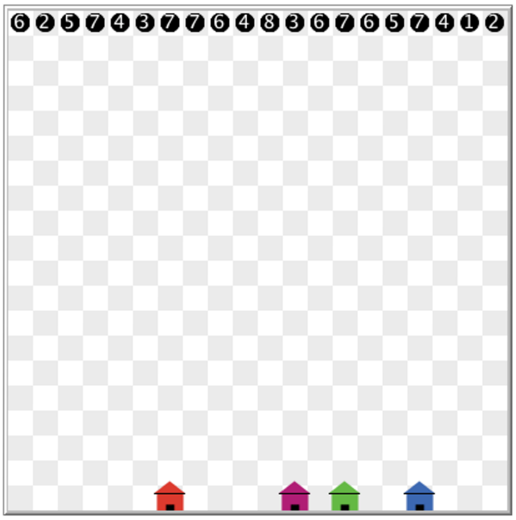
Figure 1 illustrates the general mechanics at an example run. In the following, we explain the decision logic of producers and consumers in detail.

3.3. Producer actions

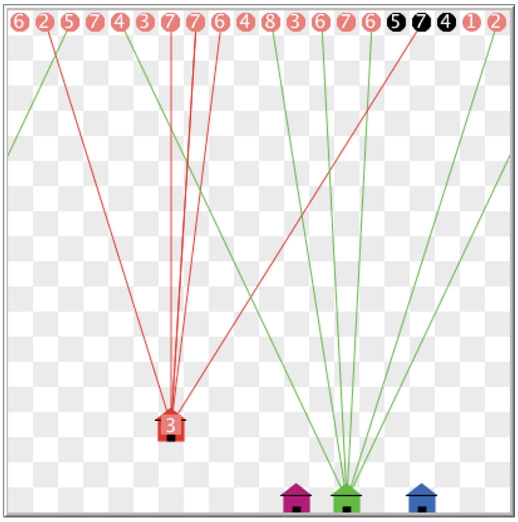
Producers invest energy, the experimental currency unit, to gain capabilities on the preference and technology level axes and to do market research. Their profit at the end of the simulation is their energy minus their start capital, as set by c_m.

In every round, producer agents generate a list of possible products that they can afford to develop. For each of those, they calculate the price p that maximizes $U_p = n_e p - (cost)$, where n_e are the number of consumers that the producer expects to buy the product at price p. They then choose to develop the product which offers the highest profit U_p at its respective optimum price. All producers pay 1 energy for the development of a product in miscellaneous costs, and additional costs depending on their type. The costs by producer type are listed in table 2, where d_x notes the distance of the new product on the preference axis and d_y the distance on the technology axis. For innovators, the reference point is the current position (knowledge) of the producer, whereas it is the position of the imitated product for lateral imitators and leapfrogs. Producers are constrained by their current amount of energy, so the optimisation is constrained by $costs \leq energy$. Each producer places one product per round, provided they found a position with expected profit $>= 0$.

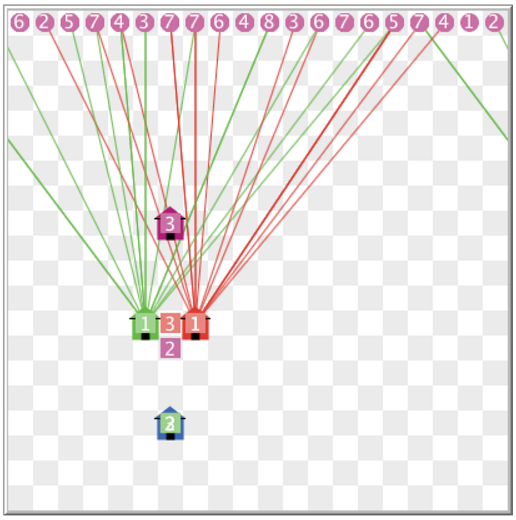
Figure 1: Screenshots of an example run



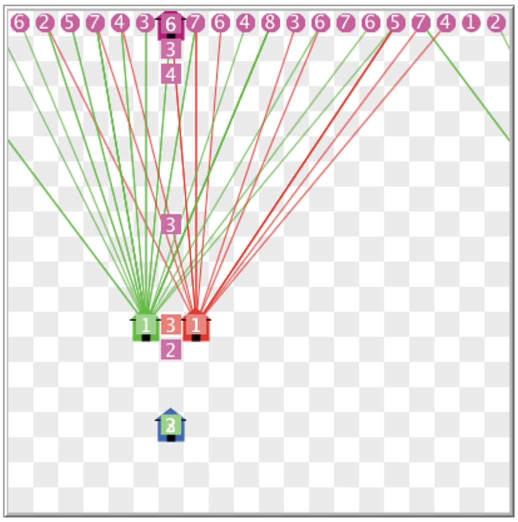
Initial setup: Houses represent the producers: Red for innovation, blue for pure imitation, green for lateral imitation and magenta for improving imitation. Consumers are dots, and the numbers on them indicate how many consumers are on that same spot.



Round 1: The innovator has created the first product, represented by as square of his colour. It's price is 3 energy. Lines from producers to consumers indicate knowledge of their position. The colour of consumers is that of the last product that they bought. Some consumers did not buy his product, because it does not provide them enough utility. In the cylindrical shape of the market, these consumers are furthest away from the new product.



Round 3: The initial innovative product was imitated by both the pure and lateral imitators, and then improved upon by the improving imitator (purple product for 2 energy). However, the innovator already created an even better version, priced at 3. Then, however, the improving imitator made an even bigger leap, whereas the innovator and lateral imitator created low-cost alternatives with slightly different preference fit. The pure imitator is left behind, because he could not identify actions with positive expected profit.



Round 12: The highest technology level was reached and the simulation ended, with the improving imitator as the clear leader, with multiple advanced product and a total profit of 794 energy. The innovator and lateral imitator went bankrupt after their investments in round 3 did not work out. Consumer surplus is 1679 and technology advanced by 1.58 levels per turn.

Table 2: Costs by producer type

Producer type	Cost function
Innovation	$1 + d_y c_m + d_x \frac{c_m}{2}$
Pure imitation	$1 + c_i$
Lateral imitation	$1 + d_x \frac{c_m}{2} + c_i$
Leapfrog	$1 + d_y c_m + c_i$

Producers take their actions with knowledge of all products and prices that were set in previous rounds, and also those that were created by producers who went first in the current round. To even out the second-mover advantage of being able to undercut a competitor before he could present his product to the consumer, producers take their actions in random order each round. In addition, products cannot be imitated in the first round they were created.

Table 3: Parameters

Parameter	Notation	Description	Base setting
Strategy type number	n_{type}	Group of parameters that set the number of producers with each strategy.	1 each
Survey cost	c_s	Cost for learning the position of one consumer.	1
Cost multiplier	c_m	Cost for move of one unit in technology level. Cost for moving on the preference axis is half. Producer receive 3x the cost multiplier as start capital.	50
Imitation cost	c_i	Cost for imitating a product.	20
Start energy	s	Energy of producers at beginning	150

3.4. Consumer decision making

In each round, consumers check if there is a product that is sufficiently better than the product they bought in the previous round to justify its price. If there is, they buy the new product. Let us note the distance from the previous product by d_{old} and the distance from the new product by d_{new} and the price of the new product by p. Then, consumers aim to maximise a utility function $U_c = d_{old} - d_{new} - p$ in every round by choosing a product. They buy if $d_{old} - d_{new} > p$. In the first round, the reference point's distance is equal to the height of the cylinder (20), which means that each consumer is willing to pay 1 energy for a product of technology level 1, fitting their exact preference. Due to the geometry of the cylinder and the random distribution of consumers, not all consumers buy the first product on the market, but instead wait until the first product that fits their needs arrives.

3.5. Optional settings

There are three optional settings which change the mechanics of the market. They can be activated separately or all together, forming the complete model.

3.5.1. Desire to upgrade

At the beginning of each round, consumers reduce their appreciation for the product that they currently have, longing for an upgrade. In practice, this means that they move their reference point d_{old} one unit further in the first round after a purchase, and 2 units further in the following round, and so on. The longer they have not made an upgrade, the faster they lose appreciation for what they have. This effectively increases their willingness-to-pay for an upgrade further and further, guaranteeing that there will be demand for improvements. However, consumers will of course never buy the same product twice or buy an inferior version of the product they already have, so their distance to a new product must still always be shorter than to their current product.

3.5.2. Technological uncertainty

Innovation is an inherently uncertain process. In the model, this uncertainty is modeled by randomizing the output of producers' R&D projects that aim to advance in technology level. If an innovator or leapfrog wants to create a product that is d_y units away from his current position, he will spend $d_y c_m$ energy on the project and the expected value for the progress is d_y. The realization of the outcome will be drawn from a normal distribution with d_y as its expected value and $(\frac{d_y}{3})^2$ as its variance. This reflects that the producers know the true expected return from of their effort, and that the variance of the outcome scales in the ambition the project.

3.5.3. Market uncertainty

In the model, market uncertainty refers to incomplete information of producers on the distribution of consumers. If this setting is activated, producers use market research and heuristics to position and price their products.

The innovation and lateral imitation types conduct market research surveys to identify consumer preferences. Surveys let producers learn the position of consumers on the preference axis, as well as their d_old. Once made, a survey persists until the end of the simulation and the information on d_{old} is continuously updated. At the beginning of each round, producers decide whether they want to conduct market research and how many consumers they want to survey. Let us note the number of users whose preferences are known to a producer by n_{known}. Then, they do up to $\frac{100-n_{known}}{c_s}$ surveys, but never spend more than 15% of their current energy on them.

All producers aim to maximise their profit on the basis of their expectations. To form expectations, producers have groups of reference consumers, whose preferences they know. When a producer calculates the expected revenue from releasing some product at some price, he calculates the number of reference consumers who would buy the product based on the history of previous product releases in the market.

For innovators and lateral imitators, these reference consumers are the consumers whose preferences they have learned through market research. If they have not learned the position of all consumers, they linearly extrapolate the number of consumers who would buy a product, i.e. if they know the preferences of 40 out of 100 consumers, they multiply the expected number of customers by 2.5.

For pure imitators and leapfrogs, the reference consumers are 100 imaginary consumers that are evenly distributed along the preference axis. The imaginary reference consumers have the same u_i value realizations as the actual consumers, which means that pure imitators and leapfrogs have correct information on population level willingness-to-pay. Throughout the simulation, they calculate which products these imaginary reference consumers would buy, and also how they lose appreciation for their current products (increase their d_{old}).

4. Results

4.1. Market mechanics

Table 4 shows the results from 1000 runs in 5 different market conditions defined by activation and deactivation of model mechanics described in the previous section.

Table 4: Comparison of market mechanics

	Base	Upgrading	Tech. uncertainty	Market uncertainty	All
Upgrading desire	-	✓	✓	✓	✓
Market uncertainty	-	-	-	✓	✓
Tech. uncertainty	-	-	✓	-	✓
Runs to max. tech.	0.0%	94.2%	88.9%	96.6%	89.9%
Tech. levels	0.06	0.89	0.98	0.91	1.03
reached*	(0.02)	(0.29)	(0.49)	(0.39)	(0.48)
Producer	-0.56	7.97	13.67	26.46	22.96
surplus*	(0.64)	(15.41)	(20.63)	(17.95)	(28.47)
Consumer	1.99	124.52	122.33	154.75	140.37
surplus*	(0.49)	(21.81)	(21.15)	(34.41)	(38.24)
Innovator	-0.23	-3.47	4.91	-6.04	-3.38
profit*	(0.48)	(4.66)	(17.75)	(4.58)	(12.66)
Pure imitator	0.02	2.29	3.15	-0.03	0.53
profit*	(0.06)	(2.90)	(3.45)	(0.43)	(2.14)
Lat. imitator	0.01	-1.82	-0.86	-6.39	-7.11
profit*	(0.21)	(12.02)	(14.49)	(2.52)	(2.54)
Impr. imitator	-0.36	10.97	6.48	38.91	32.93
profit*	(0.54)	(15.54)	(19.24)	(17.01)	(30.72)

Averages based on 1000 runs of the simulation in each setting. All runs were done with base parameter settings, except when indicated otherwise. Standard deviations in brackets. *Mean value per round.

The market does not function in the base setting. The highest technology level was not reached in any of the 1000 simulation runs. In addition, producer surplus, measured as the sum of profits over the four types, was negative on average. Consumer surplus, defined as the difference between willingness-to-pay and the actual price paid, is close to zero. The reason for this failure is that investments are not worthwhile given the cost settings in the base parameter setup (see table 3. In additional tests at lower cost settings the market functioned and the highest technology level could be reached.

The market breakdown at base cost settings does not happen when consumers exhibit a desire to upgrade, which increases their willingness-to-pay. This raise in willingness-to-pay makes investments profitable in cost settings where they were not. The three following conditions all include upgrading desire.

With regard to technological progress we find that upgrading desire increases the range of cost settings in which R&D investments are worthwhile, and that technological uncertainty increases the pace but also induces instability. Market uncertainty has a small stabilizing effect. Market uncertainty alone slows down the pace by a little, but in combination with technological uncertainty it results in an even faster pace than with technological uncertainty alone.

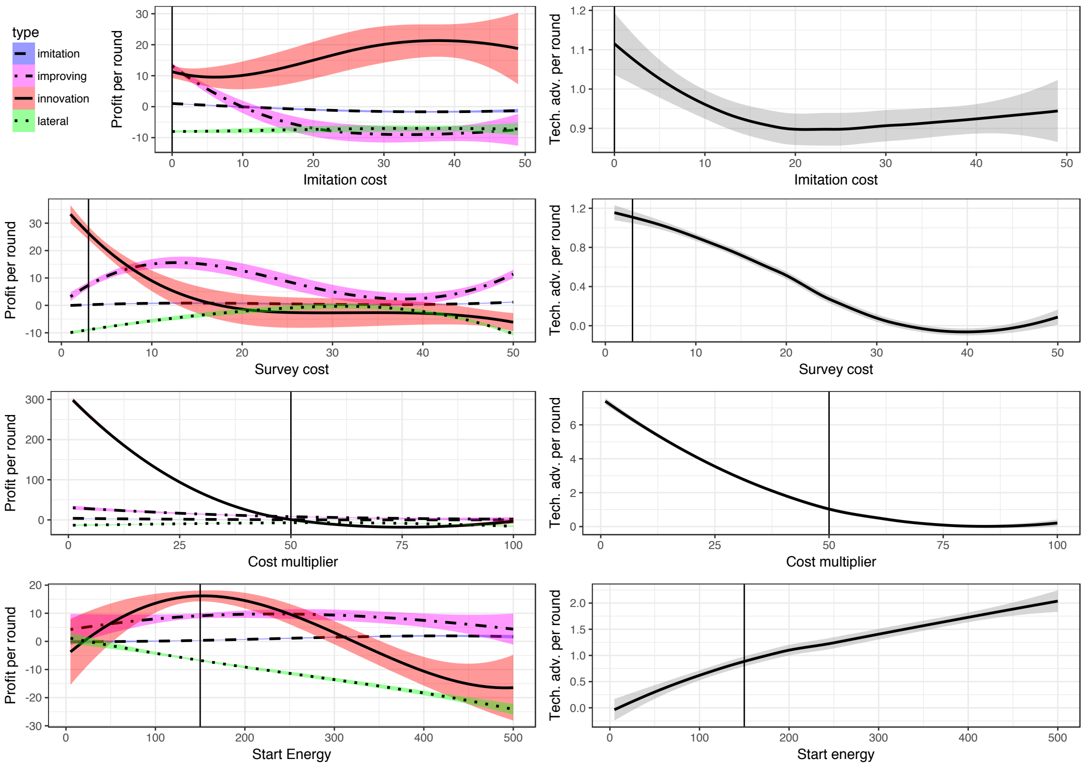
With regard to producer surplus we find again that both types of uncertainty have a positive effect in comparison to the setting with only upgrading desire. The effect of market uncertainty is greater than that of technological uncertainty. If both are present, the combined effect is smaller, meaning the effect of market uncertainty is moderated by the effect of technological uncertainty. Producer profits are unevenly distributed regardless of setting, though it is the market uncertainty which shifts profits from the innovator to the leapfrog the most. This effect can be attributed to the strategies' respective approaches to market research. Given the cost of market research (1 energy per surveyed consumer), it seems that assuming a uniform distribution of consumers is more cost effective than doing partial market research and extrapolation.

For consumers, market uncertainty is a boon, while technological uncertainty is detrimental. Still, in combination consumer surplus is higher than in the setting without uncertainty. A comparison between consumer surplus between settings with and without upgrading desire does not make sense, because the upgrading desire itself greatly increases consumer surplus by increasing willingness-to-pay.

4.2. Market conditions

We investigate the effect of parameter settings different from the ones table 3. Figure 2 shows how the distribution of producer surplus and the pace of technological advancement varies in the parameters.

Figure 2: Parameter sensitivity



Based on 10 runs of the simulation for 100 settings of each parameter, locally weighted scatterplot smoothing curves (LOESS). Colored bands show 95% confidence intervals. Base parameter settings are indicated by vertical lines.

If an imitation cost is introduced, say from effort spent on reverse engineering or on legal issues with IP, the imitation strategies suffer, and the innovator flourishes. Progress slows down, as competitive pressure is reduced.

Only the innovator can launch a first product on the market, and survey costs reduce his ability to do so. Here, we see a parallel to the results of Bessen and Maskin (2009), as overall success and welfare of innovators, imitators and consumers is dependent on success of an initial innovation. If, however, the innovator launches a first product, the leapfrog can make use of it and take the lead. In this case, assuming an even distribution of consumers is better than investing in market research.

The pace of technological progress is, as one would expect, positively associated with the amount of starting resources and negatively associated with costs for R&D. In terms of producer profits, the innovation strategy vastly outperforms the other strategies in markets where R&D costs are low. At the base setting its profit is comparable to those of other producers. The negative association between start energy and profits of innovators and lateral imitators suggests inefficient use of energy for market research.

5. Discussion

This study investigated the competitive dynamics of innovation and imitation strategies with an ABM. In the ABM, producers with heterogeneous strategies compete for the business of consumers who are constantly looking to upgrade. This upgrading behaviour is a new dynamic in durable consumer goods markets that is characterized by shortening product life cycles and high willingness-to-pay for improved versions of products that consumers already own. Upgrading behavior is modeled as a decreasing reservation price for new product upgrades over time. We investigated a variety of settings, altering parameters which reflect general industry and market characteristics, but also parameters subject to policy choices, such as the costs of imitation reflecting the strength of IPR regimes.

Consumers' desire for making upgrades, even if technical improvements do not quite justify their price, allows producers to invest in R&D, even if costs for doing so are high. Offering the latest technology is essential for success, and strategies focusing on that goal succeed over ones that do not. The drawback to imitation is a second-mover disadvantage, as suggested by Bessen and Maskin (2009).

A self-reliant innovation strategy and a leapfrog strategy were most successful. The former is superior when imitation costs are high, costs for market research are low and costs for R&D are low, whereas the latter triumphs if the opposite is true. However, if imitation costs are high, the rate of technological progress slows down, as there is a lack of competitive pressure.

We provide a simple model of competition between innovation strategies in which competing producers design innovative products to appeal to heterogeneous consumer preferences, whereas most current models are based on the assumption that the innovation has its own exclusive market potential, which is not affected by competitors' products and actions (Kiesling et al., 2012). Further, we shed new light on the currently under-researched demand side, illustrating the interaction between technology development and the demand environment in which the technology is evaluated(cf. e.g., Adner, 2004; Adner and Levinthal, 2001).

Our results also contribute to the literature related to firm level strategic decision making, by contrasting established frameworks which suggest imitation to outperform innovation strategies in industries with weak appropriability regimes (Teece, 1986). We thereby illustrate how recent development in industry dynamics might lead to situations diverging from those established frameworks at the example of a market with upgrading characteristics. In the same vein, our findings contribute to the general discussion on the effects of IPR regimes on innovation (Boldrin and Levine, 2013; Mansfield, 1986; Peeters and de la Potterie, 2006), highlighting that different market characteristics are likely to alter the effect of intellectual property protection, in terms of competitive dynamics as well as technological change.

The managerial implications are that in markets with upgrading characteristics, constant innovation effort in most cases presents a profitable and sustainable strategy. Exceptions are industries and markets with particularly high R&D costs, and high market uncertainty. The model also suggests that product development strategies based solely on imitation are in spite their cost advantages not successful in markets with upgrading behavior, where the second mover disadvantage (Bessen and Maskin, 2009) is amplified. In contrast, a leapfrogging strategy, where the first-mover advantage is sacrificed in some instances but utilized in others, is likely to be successful in the absence of a tight approachability regime.

However, in most cases, a mixed strategy of innovation and innovation appears to be most profitable, where firms make use of imitation to stay current and avoid unnecessary costs for parallel development of technologies, but also add technical innovations. Improving the technology has the potential for larger profit than horizontal product differentiation, as it can provided lead time advantages and lets a producer enjoy a monopoly for a limited amount of time.

We also provide important implications for policy makers with respect to the design of IPR policies. In line with Vallée and YıLdızoğlu (2006), our results indicate that intellectual property protection is seldom necessary to ensure technological development, but in many settings rather slows it down. In markets with upgrading characteristics, consumers' demand for better products is enough to incentivize research by the producers. Even a quasi-monopolist will invest in R&D to improve their products, because customers will only buy the next version if it provides an upgrade over the previous one. However, without competitive pressures, an monopolist is likely to implement a "salami upgrading" strategy, where upgrades are done as incremental as possible, to be justs an improvement enough to trigger a new purchase.

As in any model, the mechanics are simplifications of real interactions. In particular, innovation processes in the real world are not confined to the firm. Other actors, especially users of the product, are involved in the process (Lundvall, 2009). A further limitation is given by the highly simplified representation of IPR in the model, where the imitation cost parameter collapses all aspects of IPR tightness and reverse engineering in a single number. This simplification is necessary to prevent over complication of the model, but also means that the results are abstract. Parameters are abstract as well, for example there is no readily available industry data to use as "cost multiplier" or "survey cost". Finally, the agents in the model lack foresight; for example a consumer agent does not anticipate further product updates and does not factor them into their purchase decision.

These limitations can be alleviated through further research. Selected further mechanics could be added to the model to fit it to specific industries. An example from the mobile phone industry are mobile phone contracts between consumers and producers, that set a fixed pace for upgrading (Venkitachalam et al., 2015). Moreover, though quantitative validation is difficult due to abstraction, the model's results can be validated against stylized facts gathered in qualitative industry case studies. Another promising avenue of future research and possibilities to extend the present model is to introduce learning agents, either through imitation of their peers behavior (e.g., Tomochi et al., 2005), or through the introduction of planning and foresight. Agents' lack of foresight can be addressed by programming them to use a machine learning algorithms. Q-Learning (Watkins and Dayan, 1992) and its advanced variant Deep Q-Learning (Mnih et al., 2015) would give the agents a time horizon controlled by a discount factor, as well as the ability to learn optimal reactions for every game situation.

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A. Appendix

Table 5: Results by strategy type setup

Presence of imitators			Highest tech. reached	Mean tech. levels gained	Mean producer surplus
Pure	Lateral	Improving	Pct. of runs	Levels/round	Energy/round
-	-	-	90.6%	0.90 (0.28)	20.74 (15.29)
✓	-	-	93.9%	0.95 (0.50)	29.22 (22.90)
-	✓	-	90.3%	0.90 (0.29)	12.97 (17.11)
-	-	✓	91.3%	0.96 (0.47)	20.279 (25.82)
✓	✓	-	88.8%	0.90 (0.35)	19.77 (16.62)
✓	-	✓	92.7%	1.02 (0.46)	30.65 (24.14)
-	✓	✓	89.9%	0.92 (0.30)	13.18 (16.73)
✓	✓	✓	90.7%	1.01 (0.47)	23.63 (27.54)

Based on 1000 runs of the simulation in each setting. Standard deviations in brackets.