Pantas and Ting
Sutardja Center
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Berkeley Engineering

Home Task Robots

Abstract

We believe that home task robots will start becoming commonplace in the next five years. The field of robotics has made improvements in leaps and bounds over the last decade. More so today than ever, the various components including hardware, software, skills and research are at an inflection point, where putting them together can result in truly automated robots.

In this paper, we will walk you through our hypothesis and share our market research that points to the fact that the time is right for home task robots to take off. We will focus on *task robots that cook and clean*. We will touch upon the current players in the market and predict market trends over the next 5-10 years.

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1. Introduction

Robots, machines that carry out tasks automatically, have started becoming popular in recent years. Typically when we think of robots, we think of humanoid robots set in sci-fi movies. While a few such smart robots are available, their cost is prohibitive. In reality robotics is still early on in its hype cycle and will first go through a period where cheaper, simpler robots that help accomplish single tasks will become prevalent. In the next phase complex personal robots will ship to consumers and finally humanoid robots will become a reality. From that perspective, we believe **home task robots will start to become commonplace in the next 5-10 years.**

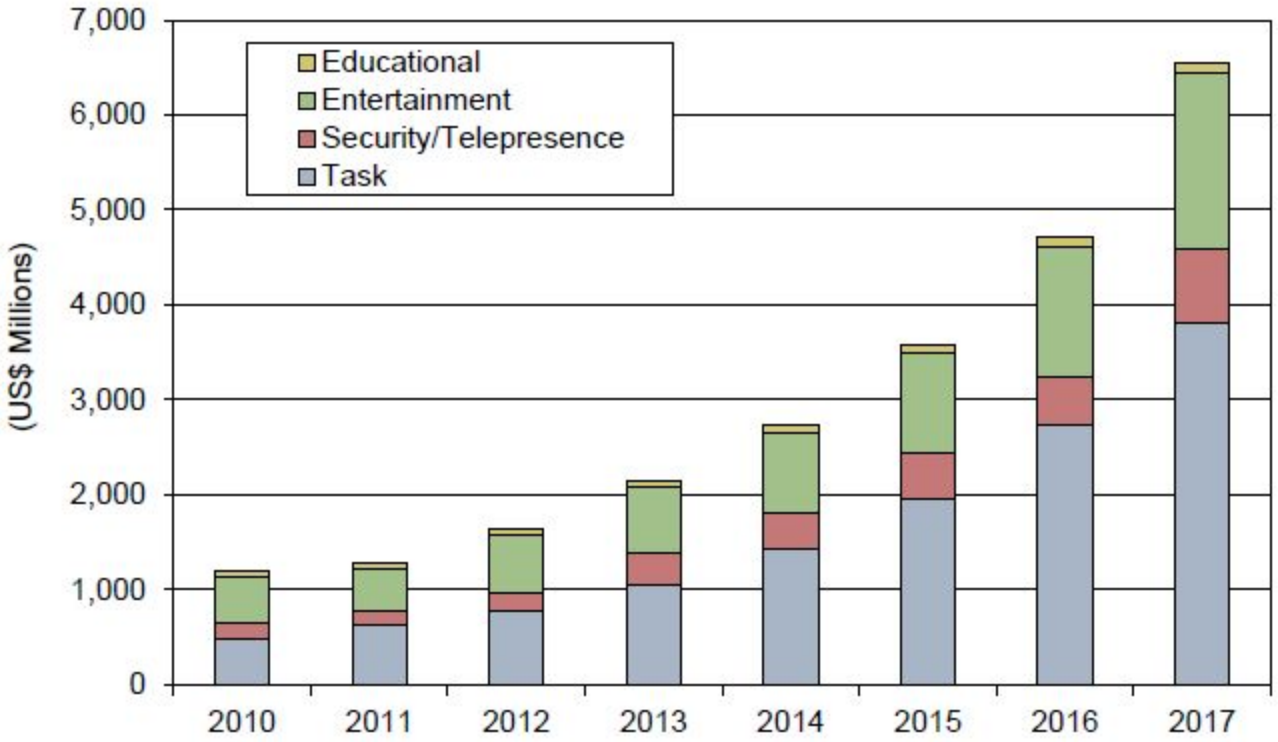

Figure 1.1 Consumer Robotics Shipments Worldwide Forecast, ABI Research 2013

The consumer robotics space can be broadly divided into educational, entertainment, security/telepresence, and task robots. We project that *home task robots* are the robots that will see the largest growth opportunities in the next 5-10 years.

1.1 Robotics in Perspective

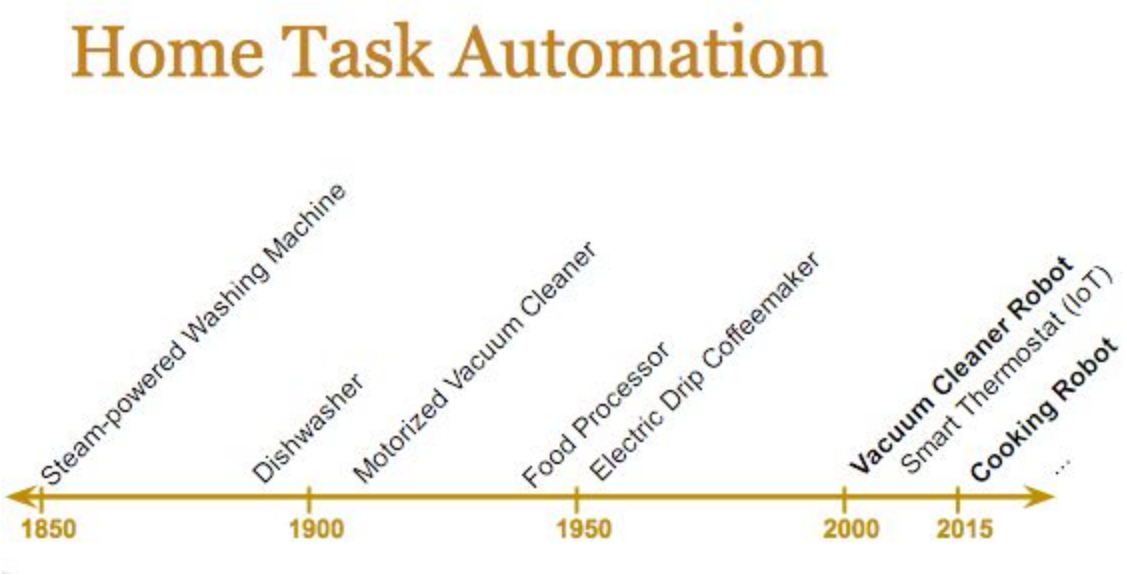

Figure 1.1-1 Home Task Automation Timeline

Home task automation could be said to have started in 1851, with the invention of steam-powered washing machines. Thereafter, came dishwashers, vacuum cleaners, food processors, and many more inventions. The next big leap this century has been in the area of smart robots, from vacuum cleaner robots to cooking robots.

We believe the robotics trend tracks analogous to the PC trend, a common reference point. We are currently at a point equivalent to where the Apple II was successful but the IBM PC and its clones had not yet made it to the market. What makes the robotics trend interesting today is that we are in the middle of a **maker movement**. This ability to DIY(do-it-yourself) or DIWO (do-it-with-others), coupled with hobby kits such as Arduino, are encouraging people to build many different kinds of robots with less overhead. There will be an explosion in innovation and commercialization of robots over the next decade or two.

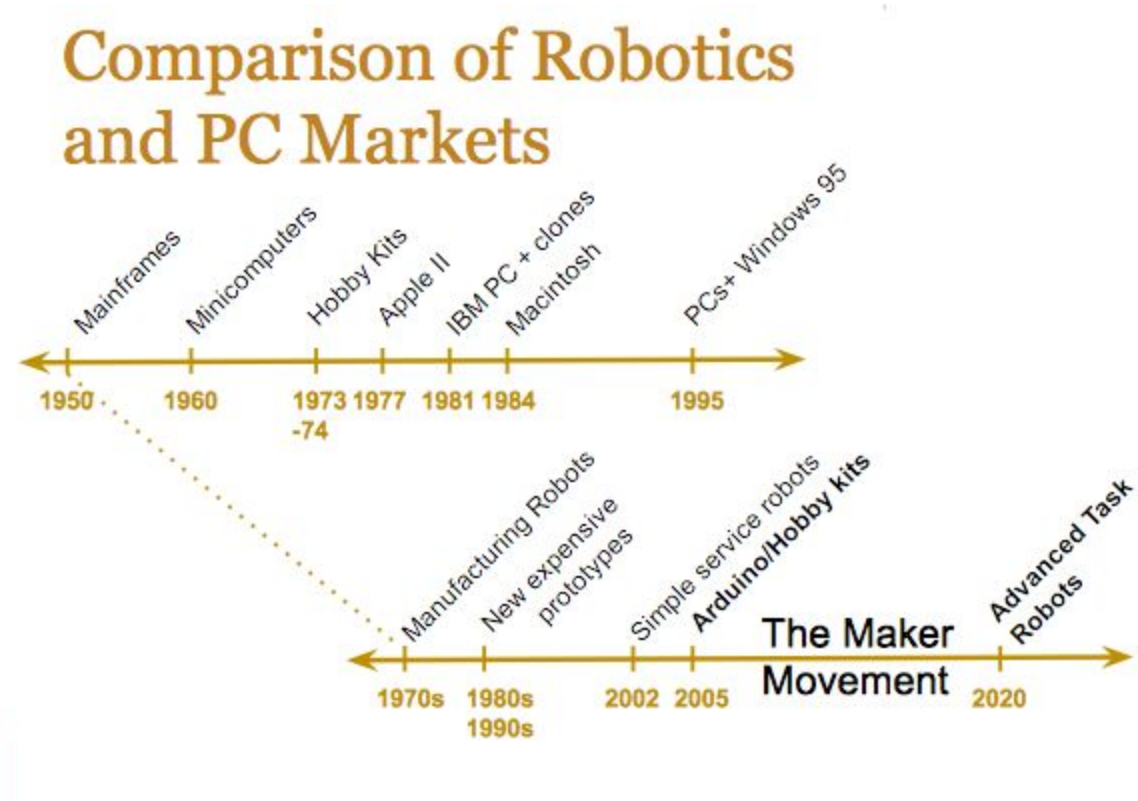

Figure 1.1-2 Robotics Market Analogous to the PC Market

2. Existing market

Task robots can be of many different kinds. For the purposes of this paper, we choose to focus on two: *cleaning* and *cooking*. While there has been significant growth in the cleaning market, the cooking market is still in its infancy.

2.1 Robotic vacuum cleaners

The robotic vacuum cleaner market is starting to grow rapidly in North America, Europe, and Asia. A sizable number of companies are entering this growing market to replace traditional vacuum cleaning due to high consumer interest. Some of these entrants treat robotic vacuum cleaners as an experimental adjacent business; others see them as an important profit center.

The total addressable market for robotic vacuums is $7.2B, with new consumption primarily driven by replacing traditional vacuum cleaners, as shown in Fig. 2.1-1.

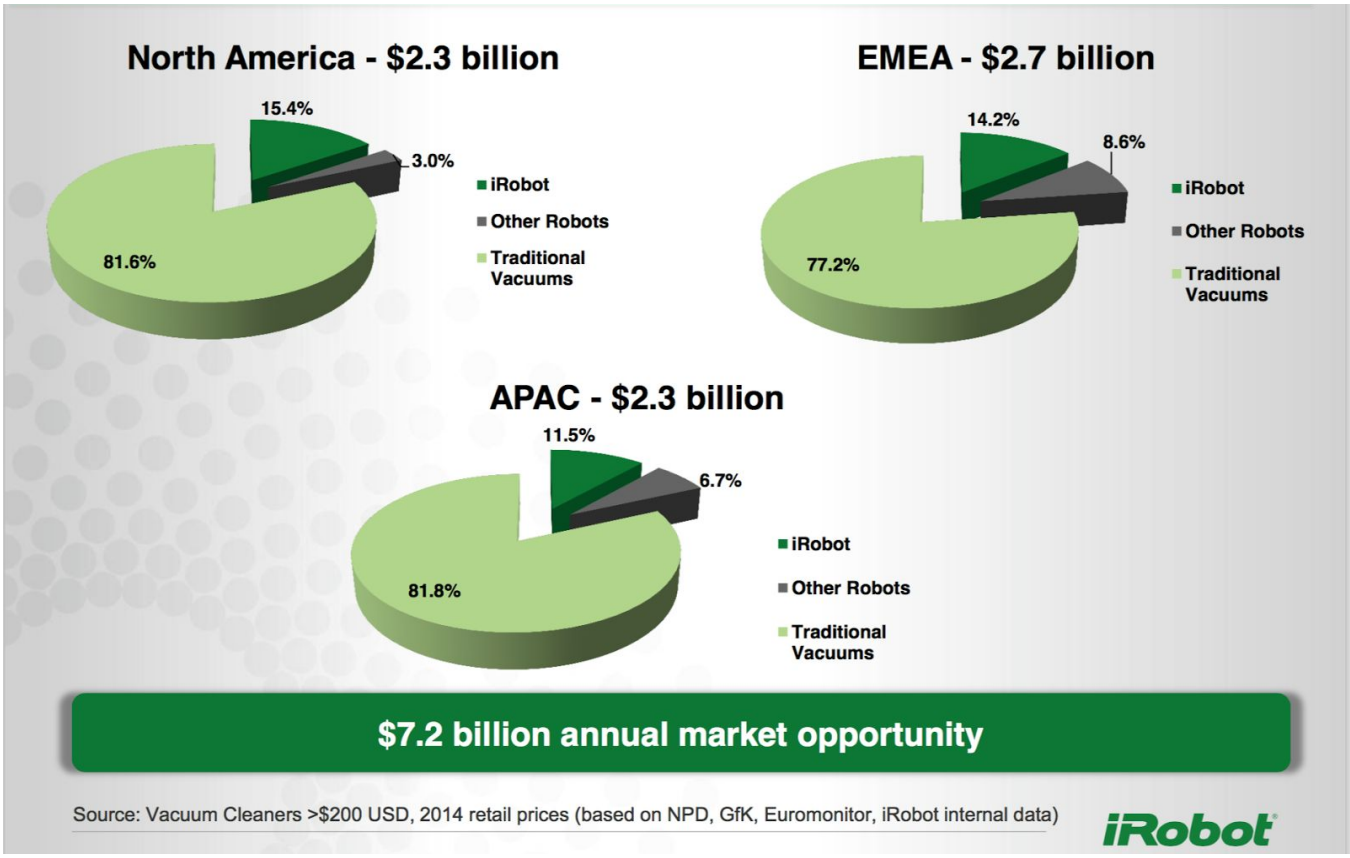

Figure 2.1-1 Total addressable market for vacuum cleaner

2.1.1. iRobot - the leader

iRobot is an early entrant in the market and has been very popular among consumers with high quality products. iRobot is considered a clear leader in this segment. The company launched its first product, the Roomba, in 2002 as a replacement for traditional vacuum cleaners. The company now has expanded their offerings to include multiple other cleaning robots that mop floors etc. iRobot is leveraging its technology and patents. As shown in Fig. 2.1-2, from iRobot's investment relations site, iRobot has 98 US patents and 188 international patents that cover its Roomba technology.

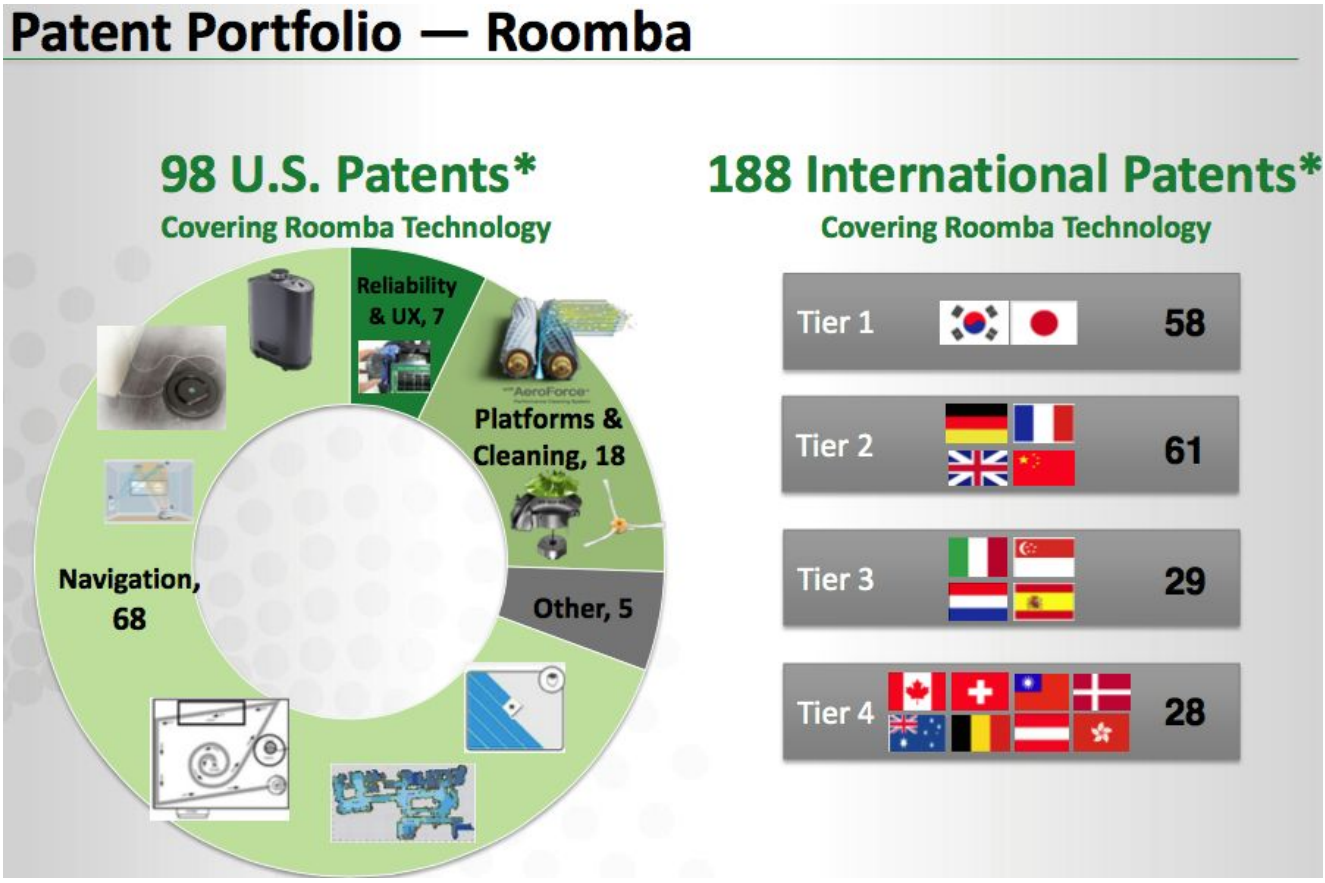

Figure 2.1-2 Total patents by iRobot for Roomba

iRobot strategy

iRobot is leveraging changes in internet technologies to accelerate its growth. This is evident based on their technology strategy as shown in Fig. 2.1-3. iRobot is utilizing the Internet of Things, cloud services, connected devices, maps, navigation, cloud robotics, and manipulation software, among other technologies, to build ever more advanced devices. The increasing availability and decreasing cost of these technologies and other robotic components, will lead to more performant and cost effective devices for customers.

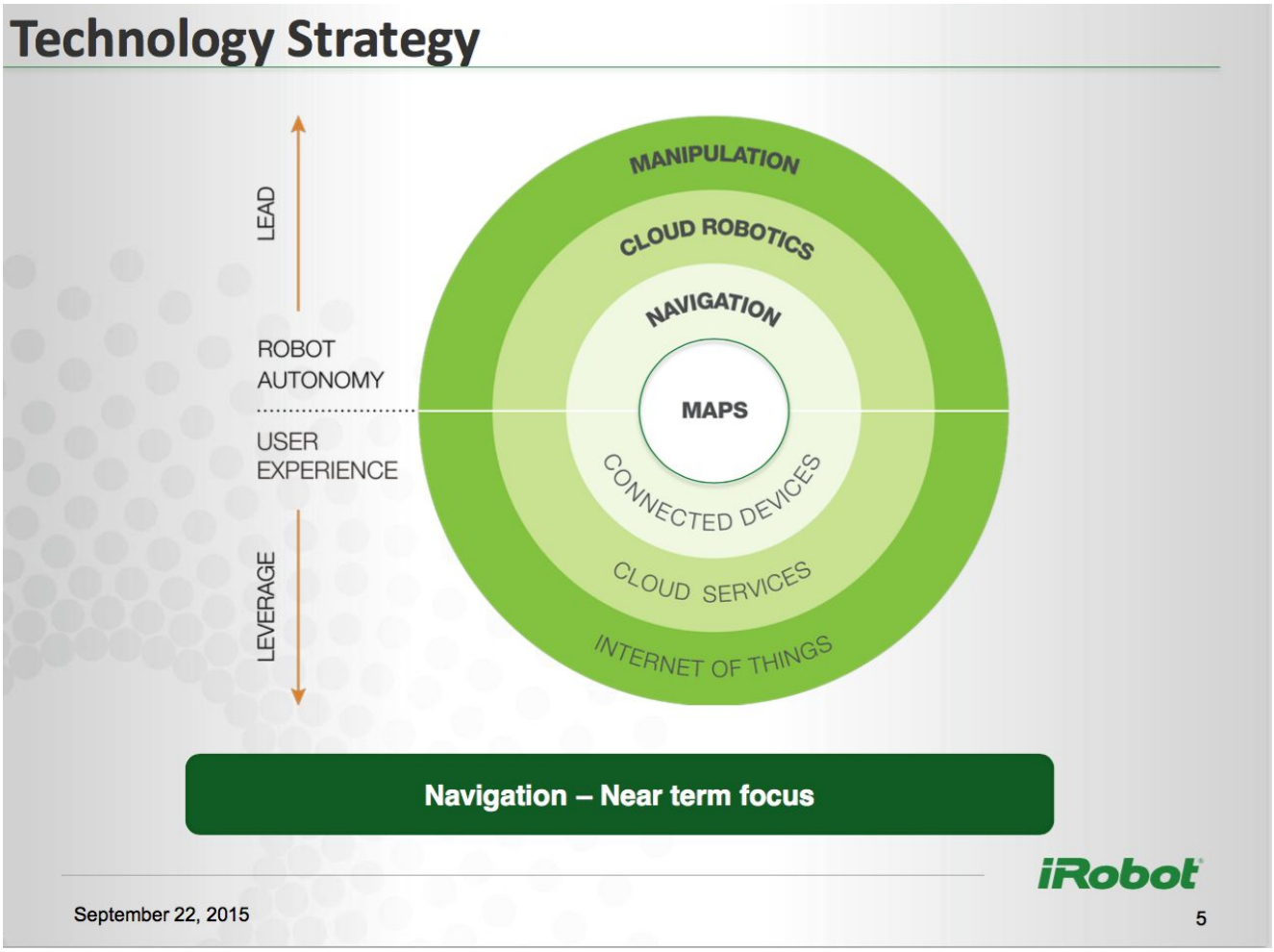

Figure 2.1-3 Technology strategy for iRobot

2.1.3. Neato

Neato Robotics, a Silicon Valley firm, launched its first robotic vacuum in 2010. Their objective is to create robots that rival humans in terms of intelligence applied to performing household chores. Their technical strategy is similar to iRobot's, aiming to drive innovation with intelligent navigation, smart home connectivity, and superior cleaning technologies.

One of Neato's innovations was to use an IR scanner at five times per second to form a basic map of the floor, space, and obstacles, leading to a much more rapid cleaning cycle than that of iRobot at the time. The latest Neato Botvac vacuum uses Wi-Fi and can be controlled remotely using an app, thereby increasing consumer convenience.

2.1.4. Samsung

Samsung is also experimenting this market but there is no data available on their current market share. Given Samsung's strength in consumer electronics, mobile phones, and the Internet of Things, Samsung has an opportunity to take a much larger market share, and undercut competitors' prices. Samsung's Powerbot vacuum cleaner robot is a strong competitor to iRobot and Neato's products.

2.2. Cooking Robots

2.2.1. Casabots

Casabots is a Silicon Valley-based startup, comprising alumni from Apple, Rambus, and Yahoo. Its objective is to provide consumers with variety and flavor by cooking multiple cuisines. Casabots has eight robotic cooking patents pending, and a working prototype, as shown on their YouTube channel. Casabots is working with a lead distributer to install 10 machines.

2.2.2. Sereniti kitchen

Sereneti Kitchen's goal is to automate cooking in the home kitchen through an innovative robotic system that cooks fresh pre-cut ingredients sold by them placed into its machine. The consumer can use their own mobile phone or tablet to select a recipe, and the machine begins cooking automatically. Sereniti Kitchen is currently a small player, with one round of funding at $150K.

2.2.3. Zimplistic

Zimplistic aims to significantly reduce the time and effort needed to make roti, a common Indian bread, with their Rotimatic machine, capable of producing one roti per minute. Zimplistic is based in Singapore and has recently raised $11.5M in funding. The Rotimatic obtained pre-orders totalling over $5M in one week's time but has not yet launched. It has a number of patents around roti making.

3. Technology

3.1 Key components

Cost is one of the major factors in the market adoption of task robots. Significant cost reduction of the main components, such as processors, memory chips, and batteries, have occurred over the last few years, as shown in the Fig. 3.1-1.

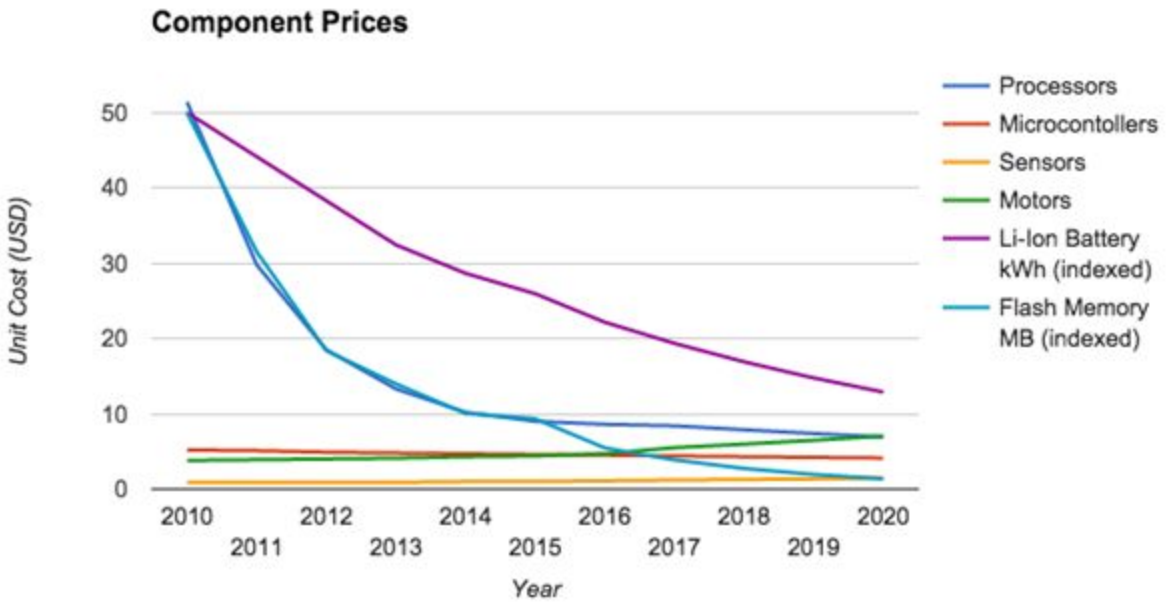

Figure 3.1-1 Robot key component price trend

3.1.1 Processors

Processors are the electronic circuitry that process programming instructions in robots by performing arithmetic, logical operations, and control. ARM-based processors from Texas Instruments, Freescale, Samsung and others are sold at $15 to $25 on average.

3.1.2 Microcontrollers

Microcontrollers are similar to processors as both are integrated circuits, but differ from the processors in that microcontrollers contain a CPU, a fixed amount of memory, and additional peripherals embedded on a single chip. Microcontrollers typically have less computational power than processors. Microcontrollers contain embedded machine language code to perform specific defined tasks. In comparison with ARM-based processors, microcontrollers cost much less, ranging from $1 to $3 each.

3.1.3 Sensors

Sensors provide robots with the ability to interact with the surrounding physical environment and with humans. Sensors can cost anywhere from a few cents to hundreds of dollars, depending on features and performance.

The most commonly used sensors in robotics fall into the following categories:

- **Vision**: Vision sensors help robots analyze objects and the surrounding environment, including distances between the robot and the object. These sensors can be used for

mapping and identification of objects or movement. Examples include cameras, depth sensors, sonar, and laser scanners.

- **Tactile**: Tactile sensors provide robots with input analogous to a sense of touch in humans. They can recognize a robot's physical interaction with its environment, determining pressure, texture, stiffness, weight, and so on.
- **Audio**: Robots use both acoustic features and linguistic features with audio sensors to provide functionality such as voice communication, voice quality, emotional change, and recognition of sounds in the environment.

3.2 Enablers

3.2.1 Cloud processing

With increasing network speed and limitations in the processing power of small robots, cloud based services for advanced features are playing a significant role in home robotics.

Commonly used cloud services include:

- **Speech recognition and natural language processing**: Google and Nuance both have cloud services in this area. With more processing power and larger datasets in the cloud, robots can provide wider range of features such as speech recognition, person identification, or even mood detection for better human-machine interaction.
- **Environment mapping and navigation**: By analyzing data from robot sensors such as sonar, laser scanner, or conventional cameras, cloud computing can provide faster and more accurate mapping of the surrounding area and aid in navigation of the robot.
- **Face/object detection and recognition**: Larger sets of image data can be stored in the cloud, enabling more accurate pattern matching to identify faces and objects.

3.2.2 Open source robotic operating systems and development platforms

Development of even the simplest robotics software can require a thorough understanding of mechanical, software and electrical engineering. This complexity slows innovation in the robotics market. Robotics researchers and the developer community have been working on open source solutions for easy and fast development of robots. Many of these libraries have been released under a BSD license and hence free to use for both research and commercialization.

Some of the commonly used open source libraries are:

- **OpenCV**: The Open Computer Vision library contains cross platform, real-time computer vision algorithms, including face detection and recognition, motion tracking, object identification, and gesture recognition.
- **OpenSlam**: Simultaneous Localization and Mapping (SLAM) is a programing algorithm that locates the robot's position in a given environment and constructs a map surrounding the robot. It has been intensively researched for autonomous robot

navigation. OpenSlam can be integrated with OpenCV or Robot Operating System (ROS).

- **Gazebo**: Gazebo provides a simulation environment that a developer can use to test their robotics software by providing simulated objects, sensor inputs to their software. This allows for less expensive testing, without the need to create physical robots and environments.
- **Robot Operating System (ROS)**: Despite its name, ROS is not an operating system. Rather, it is a collection of libraries and toolsets, including a communication framework, vision processing, and navigation. ROS was originally developed by the Stanford Artificial Intelligence Laboratory and then taken over by Willow Garage research incubator. Currently it's maintained by Open Source Robotics Foundation (OSRF).

3.2.3 Mobile technology

Robotics leverages both the hardware and the software from rapidly growing mobile technologies; this provides significant cost and time savings.

From a hardware perspective, both ARM based and Atom based CPUs with high performance and low power consumption are available from multiple vendors. Examples include Exynos from Samsung and snapdragon from Qualcomm. Small, highly accurate, power conserving sensors are becoming cheaper; common mobile sensors such as depth, pressure, proximity or thermal sensors can be all easily leveraged by robotics products.

On the software side, advanced functionality running on top of common mobile operating systems such as Android can be easily adopted by robotics products, including, for example, voice recognition, natural language processing, and face/gesture recognition.

3.2.4 3D Printing

The downward price trend in 3D printers will help developers build new prototypes or even finished products more cost effectively and quickly. This will also help consumers obtain replacement parts and enable upgraded or personalized hardware components for robots.

4. Contextual factors

There are a number of societal factors that may slow or speed acceptance of robots in the home.

4.1 Family dynamics

On the one hand, freeing up time that would be spent on household chores, such as vacuuming, allows families to spend more "meaningful" time together. On the other hand, some of the most meaningful and memorable family time is spent doing chores together, such as cooking or gardening. This may be part of why cleaning robots have so far taken

precedence over cooking robots. Overall, we believe that home task robots increase family time together; thus this aspect of them will increase adoption.

One downside to home task robots is that children will lose opportunities to develop responsibility and time planning skills if they no longer have to do chores. This aspect may decrease adoption of home task robots.

4.2 Acceptance of robots

In some cultures, for example in South Korea and Japan, robots have a certain cachet. In other cultures, such as in Western Europe, robots are seen as considerably less "cool". This coolness factor will affect the rate of adoption of home task robots in each country.

Another aspect of end users' willingness to accept robots into their homes is the ease of operation. Many users, especially the elderly (who, in many cases, are those who can most benefit from help with household chores), do not enjoy interacting with complicated machines. Features such as natural language understanding and output will help mitigate this.

4.3 Effect on the job market

Home task robots have the potential to take away work that would be done by humans. Chefs, housekeepers, gardeners, pool cleaners, window cleaners, elderly support carers, house painters, repair people, remote security personnel, and others could lose their jobs or have the scopes of their jobs significantly reduced. A proliferation of home task robots will likely lead to greater wealth imbalance in society over time. It could also lead some consumers to choose not to purchase home task robots.

4.4 Fear of artificial intelligence

Various people, including Bill Gates and Stephen Hawking, have expressed concern over machine self-determination. Task robots in their current, primitive form are unlikely to inspire fear of this sort. However, as task robots become more autonomous and multi-functional, some people may become uncomfortable with them in their homes. This is unlikely to pose a problem in the near future.

5. Today vs. Future

Our firm belief is that task robots will be commonplace by 2020 and the cleaning robots will be first to gain wide acceptance. The food market is an exciting area with a lot of potential, but the technology still has to prove itself; we believe this market will lag cleaning robots by

3-5 years. Spurred by advances in enabling technologies, we foresee a lot of new entrants in the task robot market in the coming five years.

5.1 When will task robots become mainstream?

The first commercial robotic vacuum cleaner, the Trilobite, was launched in 1997 by the Swedish company Electrolux. But it was the iRobots launch of the Roomba in 2002 that made the robotic vacuum cleaner popular. Today with improved capabilities and more attractive price point, almost 15% of money spent in North America on vacuum cleaners is today going towards robotic models; that percentage is expected to grow to more than 50% by 2020 (see Fig. 5.1-1).

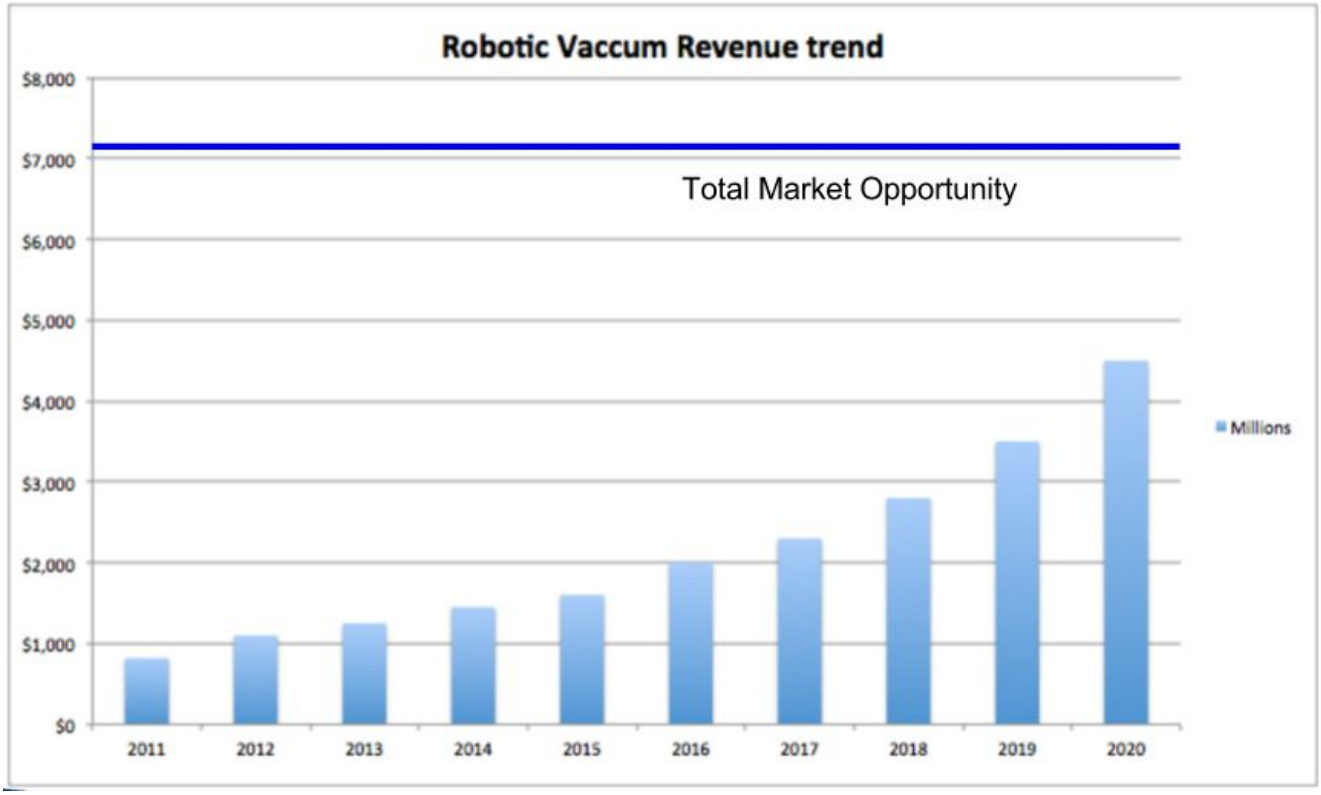

Figure 5.1-1: The growth of Robotic Vacuum Cleaners vs the total Vacuum Cleaner market.

According to the Gartner Hype Cycle (Fig. 5.1-2), the field of smart robots in general is moving towards the *peak of inflated expectations,* with an estimated 5-10 years before reaching the *plateau of productivity.* With the high and growing market share of robotic vacuums, it could be argued that they are already close to the plateau of productivity, leading the way for more task robots. This supports our conclusion that task robots, starting with

vacuum cleaner robots, will be mainstream by 2020. Although floor mopping and floor scrubbing robots are already available, we believe those will have less of a market impact than vacuum cleaner robots. Cooking robots will be very high impact, but have large hurdles to overcome; we expect that they will not be mainstream until 2025.

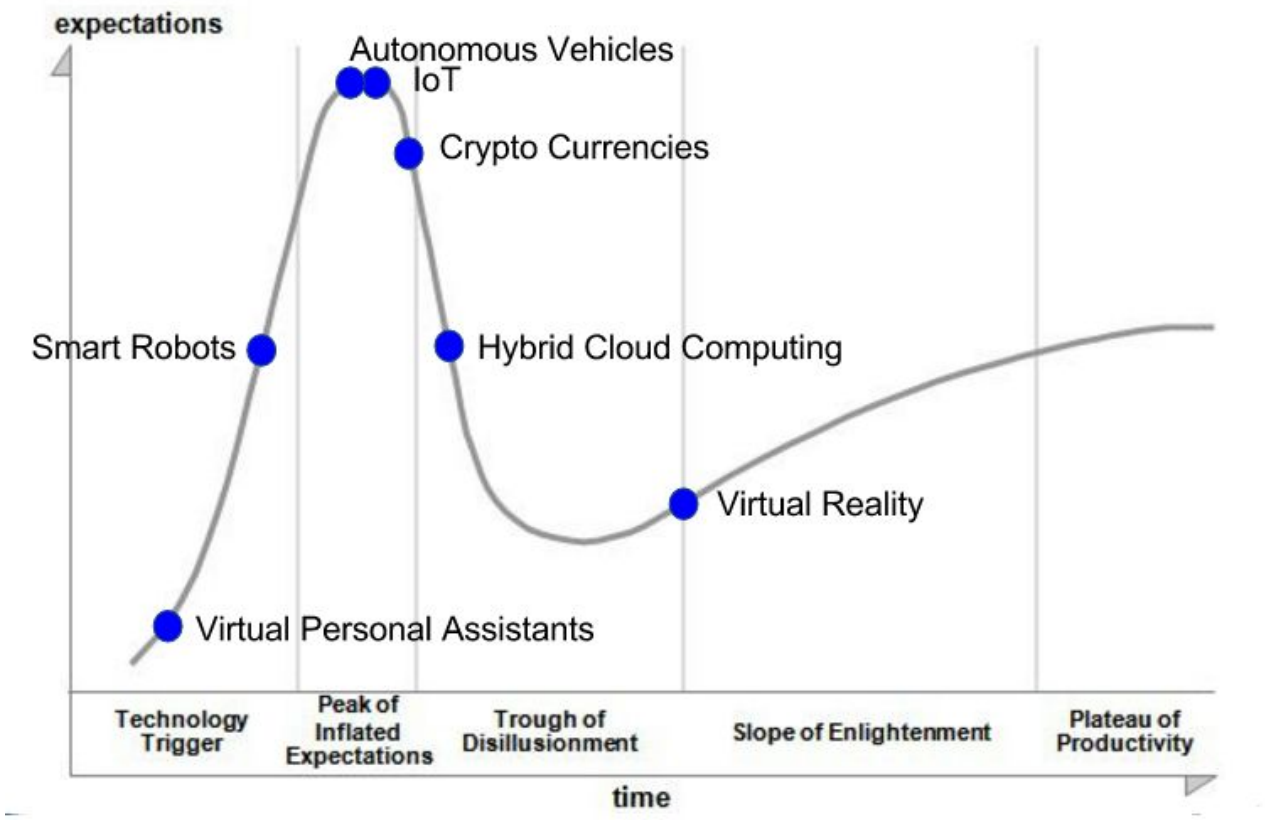

Figure 5.1-2*:* The 2015 Gartner Hype Cycle showing a subset of technologies, all with an expected 5-10 years until reaching the plateau of productivity.

5.1.2 Market and Competition

In this study we have identified three companies with different position and background.

- iRobot - Leading vendor of Vacuum Robots.
- Neato - Small company, new entrant to the market.
- Samsung - Large company, large in traditional vacaÎ@E!Suum cleaners.

iRobots now have approximately 15% of the vacuum cleaner market and 60% of the robotic vacuum market (Fig. 2.1-1). The Roomba has strong gross margins and profits, which it is able to invest in new types of task robots.

Fig 5.1.2-1*:* (from left) Electrolux Trilobite (1997), iRobot Roomba (2002) and iRobot Roomba (2015), showing a fairly mature external design. Despite price decreases and functionality improvements, there is still is room for incremental improvement.

The vacuum robotics market is maturing, but there is still room for incremental improvement, including:

- Increased reachability (e.g., through smaller size or retractable attachments)
- Reduced maintenance (self emptying, self cleaning)
- More sophisticated mapping and room awareness
- Improved battery life

Neato and Samsung pose two slightly different threats to iRobot.

- Neato tends to be faster to market with new features, e.g., mapping and smartphone integration, that may draw away consumers from iRobot. However, being a much smaller company, they will have trouble competing on price. Neato may also be hampered by iRobots' strong patent portfolio.
- Samsung, being a much larger player, can compete with iRobot on more efficient logistics and scale manufacturing. Despite being late to the game, this gives Samsung an opportunity to compete on price. Furthermore, they are not as likely to be limited by iRobots' patent portfolio, given their own patent portfolios in adjacent areas that could limit iRobots' ability to innovate.

5.2 Recommended Strategy for iRobot

In this section, we outline a strategy for iRobot to stay ahead of their competitors and and utilize their strengths in the the robotic vacuum market to gain a lead in other task robotic areas.

1. **Stay ahead**: Invest in new innovation in adjacent robotics areas to continue to be early in new markets, offsetting the growing competition in the robotic vacuum market.
2. **Secure early patents** in new areas to protect against new entrants. Current profitability of their product portfolio enables reinvestment of 13% of revenue in R&D in new products.
3. **Increase brand loyalty**: Create lock-in to iRobots products. Intrinsic brand loyalty likely low due to the banality of the tasks they currently replace. We recommend that iRobot increase brand loyalty while entering new task robotics areas by:
    - Common management interface through smartphones for all their task robotics, which will facilitate learning of customer preferences.
    - Common battery and charging stations for robot self charging will increase the cost of buying non-iRobot products for current iRobot consumers.
    - Common consumable parts between different types of robots.
    - Cross-selling, e.g., discounts on new products for current consumers.
4. **Increase efficiency through platform strategy** (will also be an enabler for creating the lock-in effect)
    - Use of cloud for sharing of mapping and sensor datas between all robots.
    - Large component, subsystem reuse between robot types.
    - Expansion in adjacent areas enabling reuse of manufacturing chain and sales channels.
    - Software component strategy enabling reuse of software between products.

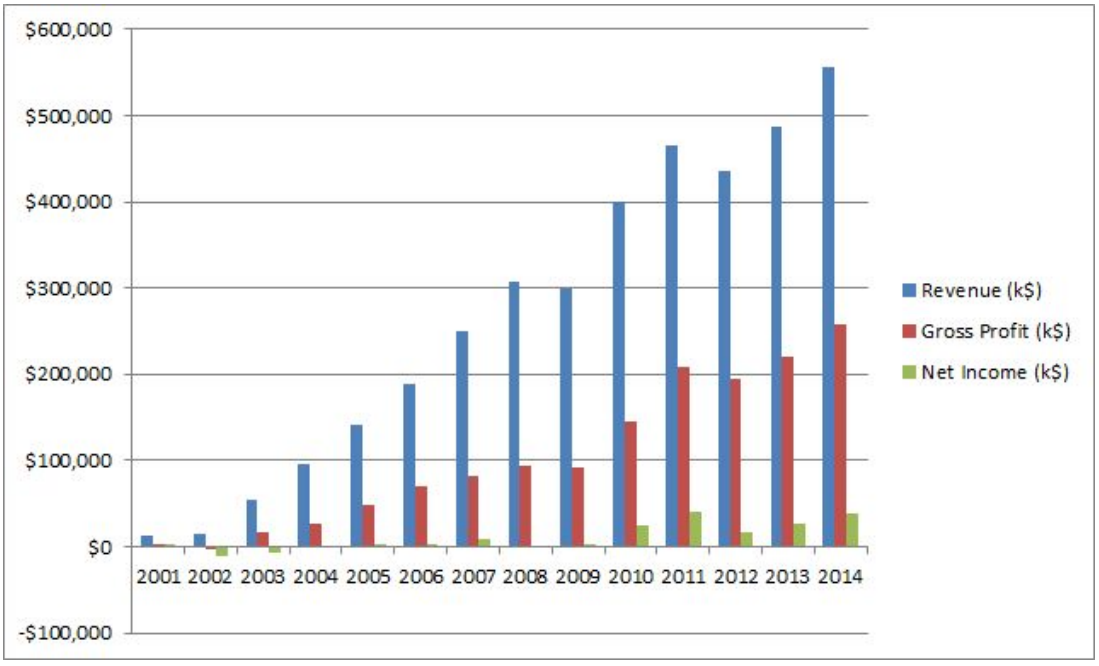

Figure 5.2-1: Revenue and profit development for iRobot 2001-2014.

5.3 Strategy recommendations for Neato and Samsung

Neato: Continue innovating more quickly than iRobot in the cleaning space. This is particularly vital in the next two to three years, while there is still enough opportunity for improvement to design and function that could sway consumers. Undercutting on price is not a winning strategy due to lack of scale to compete on price without lowering functionality and decreasing satisfaction with product. Avoiding infringement of iRobot's patents will be an issue, highlighting the importance of developing their own patents.

Samsung: Play the scale and operations game. Utilize large existing supply and sales chains in adjacent product lines when entering this market. No need to push into market until the products are "commoditized"; then go in and undercut on price. Patent infringements are less likely to be an issue due to Samsung's large patent portfolio.

5.4 Conclusions for Cooking Robots

Based on our market research, we draw the following conclusions for Cooking Robots:

- No entrants have yet proven themselves; this remains a nascent market.
- Competitive differentiation will be based on features and kinds of food cooked.
- There is still the strong possibility of new entrants taking over.

Although cooking robotics has started to find use in industrial environments, they are still expensive and usually narrowly targeting a specific type of food or parts of the process. One such example is the Momentum Hamburger Robot that has the potential for disrupting the hamburger restaurant market.

The cooking robotic market for homes is still in a very early stage, but with several startups in the process of releasing products in this area, such as:

1. **Casabots:** general cooking robot, focused on the cooking including food preparation.
2. **Sereneti:** general cooking robot, focused on the cooking step, but using chopped food.
3. **Rotimatic:** specialized in making rotis.

Similar to vacuuming, cooking robots currently solve the problem of cooking, but may need human assistance with preparation and cleanup. To increase the appeal of cooking robots, more features such as food prep, cleanup, and more cuisine variety may be needed.

The rapid technology development and enablers described earlier make it likely that we will see a rapid technology innovation in this area in the coming years, increasing consumer appeal.

Given the market potential in food robotics, and technological enablers and evolution, we believe that the field will attract many new entrants. As there is no clear market leader, and financial data is not available for these startups, we believe that the it is too early to pick winners and losers.

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National rankings consistently place UC Berkeley's undergraduate and graduate programs among the world's best. Berkeley is home to top scholars in every discipline, accomplished writers and musicians, star athletes, and stellar scientists—all drawn to this public university by its rich opportunities for groundbreaking research, innovative thinking and creativity, and service to society.