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The Future of Food: Insights Into the Economics and Commercial Viability of Lab-Grown Dairy

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Abstract
In a world where sustainably developing is becoming increasingly essential, the role of lab-grown dairy has come to the fore. Revolutionary scientific developments have led scientists to create methods that can efficiently and sustainably produce a lab-grown dairy product that is chemically and structurally the same as cow milk. This milk, aside from having a range of health benefits, is far more sustainable from an environmental and economic standpoint, eliminating the need for an economically inefficient dairy industry, marred by large dairy farms, environmental degradation and a cumbersome and expensive supply-chain. Lab-grown milk is also likely to reach commercial viability given the anticipated consumer sentiment surrounding it – it has received positive reviews, as substantiated by media sources as well as a primary survey conducted by the authors. The industry has shown signs of growth in foreign markets, but its Indian pioneers must tread with caution, in a market where they are likely to encounter the behemoth that is Indian Bureaucracy, the likely spread of misinformation, and an economy greatly reliant on the dairy industry.Keeping this in mind, this review paper will explore the economics of lab-grown dairy, establishing why the dairy industry is economically unsustainable and allocatively inefficient. It will then delve into the current and future market of lab-grown dairy, concluding with some policy recommendations that could be employed to seamlessly implement this nascent and potentially revolutionary technology.
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1. Introduction

The dairy industry is one that is rapidly developing, owing to increased consumerism and the need to satisfy growing populations. In 2020 alone, Indians consumed a mammoth 81 million metric tons of milk (Shahbandeh, 2020), a sizeable majority of which was conventional buffalo or cow milk.

While drinking a glass of milk may not seem harmless, the process of its production is one that has a host of adverse implications on sustainable development, primarily impacting the environment and proving to be a major cause of animal cruelty in large dairy farms globally. The process is one that is also not sustainable from an economic standpoint This introduction therefore delves into the problem with conventional dairy, and establishes a concrete rationale for the consumption of lab-grown dairy.

1.1 The issue with animal-based dairy

While there is no merit in arguing that the animal-based dairy sector does not greatly contribute to national economies, providing employment for millions globally, it is greatly flawed, owing to its unwieldy supply-chain. The supply-chain (which will be discussed in more detail in Section II) involves multiple stakeholders, ranging from the milk farmers themselves to collection centres, milk agents and retail suppliers. This makes it extremely hard to manage, and increases the scope for risks and challenges at the procurement stage and production stage, as well as for logistics managers and small suppliers. The costs of production and selling price are consequently exorbitant, as every facet of the supply-chain needs to be adequately financed to keep the sector up and running. It is hence no surprise that even large, monopolistic companies like Amul often resort to price hikes, with the company announcing a 2 rupee increase in milk prices, citing "high input costs" (India Today, 2021). These price hikes will also hurt consumers, increasing deadweight losses and overall reduced social welfare, explained in section II. Therefore, from an economic standpoint, the main issue with animal-based dairy is its large supply-chain, which is inevitably not sustainable in the long-term.

Aside from its unfavourable economic shortcomings, animal-based dairy as an industry also has egregious impacts on a host of key social and environmental factors.

Firstly, bovine waste products have negative impacts on the environment, exacerbating the ever-growing issue of climate change. The release of methane by gastroenteric fermentation in dairy cows is a significant contributor to greenhouse gas emissions. Bovines also release carbon dioxide and nitrous oxides in smaller amounts, which further pollute the air. The World Widlife Fund (WWF) reports that the average dairy cow

releases 17 gallons (64.4 litres) of manure, which releases nitrogen and phosphorus compounds into water bodies (WWF, 2019). This causes severe water pollution, resulting in 'eutrophication', where algal bloom and oxygen deprivation take place, reducing populations of marine organisms. In addition, manure also releases ammonia and hydrogen sulphide, which irritates the respiratory system, and could prove potentially lethal at high doses. Conventional dairy production is also highly water-intensive: bovines consume several gallons of water each day, draining high-capacity wells and aquifers; as a result, rivers and other water bodies dry up (WWF, 2019).

Secondly, in addition to the environmental drawbacks of the dairy industry come a range of social impacts, such as animal cruelty. All over the world, dairy cows undergo barbaric treatment, enduring painful mutilation and cruel transport. Branding, dehorning and tail docking are, among other methods, unfortunately widely prevalent in dairy farms, and cows and buffaloes are often subjected to extreme claustrophobia during transport (Chatterjee, 2017). Lives of pain and suffering are then brought to an excruciating end – an estimated 300 million cows were killed for dairy or meat in 2016 (Sanders, 2018). Dairy farm workers are also subjected to poor working conditions, such as limited ventilation, smells and odours, as well as low lighting (Rupa and Sharma, 2017). Dairy farms that deal with large numbers of dairy cows also increase the risk of workplace injuries.

Finally, while cow milk does have many nutritional benefits, such as reduced risk of diabetes and better heart health, the American Institute of Cancer Research, in a 2007 study, concluded that there is a link between consumption of excess calcium and certain cancers, primarily ovarian and prostate cancer (Abid et al., 2014). Moreover, cow milk has a higher lactose content than alternative milk, as a result of which around 65-70% of the world's adult population, which are lactose intolerant, could suffer from symptoms of lactose intolerance (Bayless et al., 2017). Further, cow milk also has a relatively high cholesterol and saturated fat content in comparison to dairy alternatives, which bode poorly for cardiovascular health (Abid et al., 2014).

1.2 Why lab-grown dairy?

The ecological, social, and health drawbacks of conventional dairy sources have brought alternative dairy into the forefront: it is a multi-billion-dollar market (Hall, 2021) poised to continue growing as demand for it rises. The alternative dairy market itself is divided into multiple different segments, such as plant-based dairy alternatives, ranging from soy milk to oat milk, as well as lab-based dairy alternatives. While all these individual types of alternative dairy vary in terms of production processes and supply-chain, there is no denying that they are better for the environment and will help create a more sustainable world.

It is important to consider that lab-grown dairy is produced by a process known as microbial fermentation, which uses microorganisms' ability to produce substances when given a DNA sequence (Perfect Day, 2021). This method is abundantly more efficient than both conventional dairy production as well as plant-based dairy alternatives, owing to the fact that microorganisms such as bacteria multiply within minutes, can produce a range of complex molecules, and have extremely simple requirements, such as needing lower temperatures to function optimally (Gallegos, 2018). This makes microbial fermentation in labs a far more efficient method of dairy production than others: more product in less time. This rapid and highly efficient method of production, catalysed by a highly manageable and seamless supply-chain, is far more economically sustainable than its animal-based counterparts. This, in the long term, may help reduce food insecurity, as milk will be mass-produced on a far larger scale than before, and when prices and costs of production decrease, the issue of price-hikes and depleted social welfare will become virtually non-existent.

Lab-grown milk also has a host of environmental benefits. American alternative dairy start-up Perfect Day revealed that their lab-grown whey protein was "85-97% lower in greenhouse gas (GHG) emissions compared to traditional production methods of whey protein" (Perfect Day, 2021). Lab-grown milk produces a mere fraction of the waste produced by conventional cow-based milk, and is not as water-intensive. It further goes without saying that lab-based milk will alleviate the need for cows and other bovines to endure barbaric treatment in underdeveloped dairy farms.

Lab-grown dairy is also healthier than conventional bovine dairy, as it does not contain lactose, and is hence more suitable to the lactose intolerant population. Further, lab-grown milk also has the same fat and protein content and quality as cow milk (elaborated upon in section III under "competitive advantages of lab-based milk"), which means no nutritional benefits are lost in the production of lab-based milk (Perfect Day, 2021).

To conclude, lab-grown milk has a wide range of benefits compared to conventional dairy, and is a far more sustainable alternative when considering the United Nations Development Program's (UNDP) Sustainable Development Goals (SDG), helping achieve SDG-2 (No Hunger), SDG-3 (Good Health and Well-being), SDG-8 (Decent Work and Economic Growth), SDG-11 (Sustainable Cities and Communities) and SDG-13 (Climate Action) faster and more efficiently (UNDP, 2015). Keeping this in mind, the ensuing research paper delves into the methods that could be used to develop lab-grown dairy, comparisons to other alternatives, its commercial aspects, and, finally, its future in the world.

2. Methodology

In order to write this research paper, I conducted secondary research into different companies that have produced both lab-based and plant-based milk and milk products, such as Perfect Day, New Culture, Remilk and Oatly. This research gave me an insight into methods of production as well as supply-chain of lab-grown dairy, and helped me draw comparisons between the different types of alternative milk. This research further sensitized me to the environmental as well as economic benefits of lab-based milk. Furthermore, I also used a range of published sources taken from reputable, peer-reviewed journals, as well as patents, to further gain an understanding of the molecular components of milk as well as innovations in biotechnology that have taken place. To gauge consumer sentiment with regard to lab-grown dairy, I also conducted an independent survey, using the platform *SurveyMonkey*. The results as well as limitations of the survey are detailed in Section 5.6.

3. The Economics of Conventional, Animal-based Dairy

India ranks first in global dairy production, with the industry contributing over 17% of the agricultural GDP (Press Information Bureau, 2021). Its value chain is thereby extremely specialized and developed, with companies such as Amul and Britannia having devised and consolidated an extremely intricate method to collect and distribute their dairy products. This method—albeit long-established and highly profitable—is rife with potential risks and challenges, which would otherwise be non-existent for lab-based dairy products.

A detailed overview of the animal-based supply-chain is provided below:

- **Tier 1 - Collection and maintenance:** This entails the provision of fodder and other animal feed needed for the cattle, as well as the requisite veterinary aid required (Singh, 2018). Large volumes of water are also required for overall cleanliness, maintenance, and for the cattle. Large, medium, and small-scale dairy farmers then milk the cows/buffaloes to obtain raw milk. The milk cold-chain then begins when this raw milk is transported to collection centres, known in India as "Milk Cooperative Societies." There were an estimated 190,000 dairy cooperatives in India, as of 2019 (Statista Research Department, 2020).
- **Tier 2 – Processing and logistics:** Milk collected by these cooperative societies are then transported in bulk to large processing plants, wherein the chilling, processing, pasteurization, and packaging of milk takes place (Singh, 2018). The milk is analysed for its water, fat, and protein content by machines in these plants, and, under the adequate and optimal pH and temperature levels, processed and purified. The milk is now ready to be transported through various distribution channels, or is converted into secondary milk products such as curd, ice-cream, etc (Singh, 2018). These dairy products are subsequently transported from one place to another in refrigerated vehicles, which contain insulated containers.
- **Tier 3 – Distribution channels:** Processed, pasteurized milk is then finally distributed to consumers via milk agents, or through retail stores or online marketplaces.

The supply-chain discussed above is remarkable not only for its speed and relative efficiency but also its intricacy and size—the market has expanded and scaled immensely since the end of British colonial rule, employing hundreds of millions of Indians, directly and indirectly. However, the main problem with the industry is just that—its size. In developing nations such as India, a substantial share of milk is marketed and channelled through the informal sector, which is not under the purview of governmental regulation or licensing. As a result, most often in poverty-plagued rural areas, people tend to buy dairy products at far lower costs than the market retail price, owing to the fact that they are less likely to pay for the costs of packaging and transportation. Aside from the issues stemming from the growth of informal distribution channels, the supply-chain is also highly susceptible to the following challenges (Singh, 2018; FAO, 2021):

- Manipulation in the quality of milk during farming and processing
- Seasonality—seasonal spikes in demand owing to evolving user attitudes
- Highly logical payments based on fat and solid non-fat (SNF) content
- Epidemics/diseases that may harm animals
- Low genetic potential of bovines
- Inadequate feeding material
- Structural employment issues—imbalance between skilled and unskilled labour
- Manipulation and exploitation of dairy farmers
- Increase in fuel prices resulting exorbitant transportation costs

Social Welfare and Deadweight Losses

The risks posed by the supply-chain can all contribute to increased input costs of dairy products, a significant issue faced by even the largest dairy companies; the Food and Agriculture Organization of the UN (UNFAO) further affirms that challenges such as the cost of feed significantly influences the cost of milk, impacting

production costs and also indirectly raising land prices (FAO, n.d.). These rising fixed and variable costs inevitably have spill-over effects on the rest of the supply-chain, sometimes prompting companies to implement price-hikes. *Amul*, on June 30th, 2021, announced a nationwide price-hike of 2 rupees, citing "high input costs" as a reason (India Today, 2021). These price-hikes are not isolated instances by any means, and are becoming far more frequent, thanks in part to increased consumerism and inefficiency at the Tier-1 level.

The economic implications of price-hikes are a step in the wrong direction for social welfare; basic economics reveals that even a small increase in the price of a commodity as essential and large-scale as milk can result in serious deadweight losses (DWL). This can be explained using a simple supply/demand and social-welfare model, which conveys that higher prices reduces the number of people that are willing and able to purchase a given quantity of dairy. This means that overall "consumer welfare" decreases (a smaller proportion of the population is able to buy dairy products) and increased "producer welfare" increases (producers can sell their product at a price higher than the one they were willing and able to pay for. The net effect of price hikes, though, is that overall welfare (consumer + producer welfare) decreases. This decrease in overall welfare, termed "Deadweight Loss", is unfortunately prominent in the animal-based dairy industry in India currently, whenever price-hikes owing to rising input costs in the supply-chain are implemented. The supply/demand model that explains this phenomenon is Figure 3.1 in the appendix.

Economies of scale

Economies of scale are the cost advantages that companies obtain when they expand their scale and traction, reducing their production cost and thereby their selling price over time. This occurs when input costs decrease, for example once companies gain more bargaining power with their suppliers, or gain an infusion of capital. There are multiple types of economies of scale, dependent on the fixed and variable costs, labour, and capital equipment required.

The animal-based dairy industry is likely a technical economy of scale, owing to the fact that it involves large capital equipment costs (machinery in processing plants, transportation) and high fixed costs (land rent, payment of dairy farmers, etc.). It therefore has lower economies of scale than its agricultural counterparts such as livestock, owing to its exorbitant input costs. This has been thoroughly substantiated by the FAO, which reported that the "high labour input" of the animal-based dairy industry makes it have "lower economies of scale than other agricultural systems." Furthermore, the FAO also concluded that a dairy farm with 9 cows in India has similar labour costs to a dairy farm in the USA with 350 cows, demonstrating the relative exorbitance of labour input costs in India (FAO, n.d.). As a consequence, the animal-based dairy sector in India is one that needs to be highly subsidized to keep costs low.

On the contrary, the lab-grown dairy sector, in the long-term, is expected to have far higher economies of scale than the animal-based dairy sector, as it is likely that the relatively lower supply-chain costs will be substantially low. This is because the entire Tier-1 stage highlighted earlier is non-existent: the milk can be produced, processed, and transported from the lab itself. This will substantially lower input costs as fewer employees will need to paid. That being said, the current size of the animal-based dairy industry, at least in India, will make it difficult for lab-grown dairy to get integrated into the market share. Therefore, economies of scale for lab-based dairy is likely to not occur until the sector 1) attracts significant investment and/or subsidization and 2) adequate consumer traction.

Therefore, to conclude, fundamental economic concepts as well as an analysis of its unwieldy supply-chain thoroughly explain that the current animal-based dairy sector is economically unsustainable, and is marred by risks that would otherwise be eliminated by the lab-grown dairy sector.

4. The Market for Alternative Dairy and its Commercial Viability

The various benefits offered by Lab-grown dairy from a personal health as well as sustainability standpoint have made the sector one that is poised to grow financially in the years to come. Startups that have already produced lab-grown dairy have attracted significant investment from Venture Capitalists and investors, a further testament to the potential growth and scalability of Lab-grown dairy. Keeping this in mind, the ensuing section will delve into the companies that have penetrated this market so far, the competition and alternatives they face, regulatory policies in place with regard to lab-grown plant proteins, as well as the prevailing consumer sentiment.

4.1 Current players in the market

While lab-grown dairy has not yet hit shelves in the Indian subcontinent, startups have penetrated the American (*Perfect Day, New Culture*), British (*Better Dairy*), Singapore (*TurtleTree Labs*) and Israeli (*Remilk*) markets. While each of these companies are extremely small-scale and yet vying for traction in their respective markets, they have each received significant investment.

Perfect Day in particular has scaled the largest so far in terms of size (158+ employees) and revenue growth, reaching an estimated $42.7 million in revenue in 2020 (Crunchbase, n.d.). It has also received 6 rounds of total

investment, totalling a total of $361.5 million, from noted investment firms such as Temasek Holdings and Horizon Ventures (Crunchbase, n.d.). The product they produce, a whey protein powder, has since been used extensively by many dairy companies such as BraveRobot, Graeter's, Nick's, Smitten Ice Cream, and the Urgent Co., which produce ice-creams as well as a range of frozen dessert products (Perfect Day, n.d.). The second-most prolific company in this sector is the Israeli *Remilk*, receiving $11.3 million in investor funding by 11 investors (Crunchbase, n.d.). Therefore, the market is currently yet growing, and companies are yet seeking investment to expand and gain more consumer traction in the future.
A detailed overview of the current players in the market is provided in the appendix, labelled Table 1.

4.2 Alternatives to lab-grown dairy

A major threat to lab-grown dairy, aside from conventional cow dairy itself, is plant-based milk. This method, which involves soaking and grinding plants and then adding the requisite minerals, vitamins, and waters, has given rise to almond, soy, rice, coconut, hazelnut, walnut and oat milks (McClements et al., 2019). Plant-based milk – which has grown substantially with veganism gaining popularity – is far more developed and prolific compared to lab-grown dairy, and has also made a foray into the Indian market, with companies such as *SoFit* and *Nutriva* selling a range of plant-based milks. Foreign companies such as the Sweden-based *Oatly* have also gone global, selling in the American, European, Chinese and UAE markets.

Most plant-based companies have received positive feedback from consumers, but lab-grown dairy has not seen enough traction yet.

4.3 Regulatory Policies

India – In India, the dairy industry is one that is very closely scrutinized, owing to the fact that it contributes to an estimated 4.2% of the national Gross Domestic Product (Hussain, 2020). Governmental ministries, such as the Ministry of Animal Husbandry, Dairying and Fisheries, National Diary Development Board and the Food and Safety and Standards Authority of India, are the entities that regulate the dairy industry. These ministries often investigate the food safety and adulteration of milk, and take strict regulatory action, including life imprisonment, in Uttar Pradesh, West Bengal and Odisha. An FSSAI survey in 2019 revealed that approximately 41% of dairy samples failed some type of safety parameter, such as contamination (Indian Express, 2019). Moreover, the pollution and severe environmental threats posed by the dairy industry have prompted government bodies such as the Central Pollution Control Board issuing guidelines to investigate water pollution caused through large dairy farms, determining the quantity of methane in water bodies, and the handling of animal waste (Press Trust of India, 2019). Therefore, the Indian government has, in the past, proved that the dairy industry will be strictly regulated; as a result, the government will most definitely investigate the nutritional content and environmental impacts of lab-grown dairy once it hits the market. This makes it highly likely that the government will accept lab-grown dairy as an alternative to conventional dairy sources.

That being said, India has perennially imposed tariffs on foreign dairy imports; this has, in the past, discouraged foreign players from penetrating the Indian dairy market (Suneja, 2020). A noteworthy example of this is Danone's failed diversification into India in 2018 (Mitra, 2018). The imposition of trade barriers has therefore shown that India would, at some point in the future, not be open to accepting foreign alternative milk players from entering the market. This means that in order for lab-grown dairy to flourish in India, it would most likely require domestic production. Another reason the government would not allow lab-grown dairy to hit the market is that it would completely disrupt the highly specialized and intricate dairy industry, which employs over 8 million dairy farmers (Parida and Yadav, 2020). This would result in widespread unemployment as well as financial losses. Therefore, while the government is likely to recognize and accept the nutritional benefits of lab-grown dairy in India, its prior track record with foreign dairy imports and the vastness of the dairy sector mean that lab-grown dairy will need to wait for many years before it can be rolled out and scale quickly.

Foreign Markets – In markets where these products have already hit shelves, national regulators have paid more attention to the microorganisms that are used to make the lab-grown dairy than the product itself. This has not proved to be an issue so far, with *Perfect Day* getting their Generally Recognized as Safe (GRAS) determination for their non-animal whey protein accepted by Food and Drug Administration (FDA), which sent a 'no questions/objections' letter in April 2020 (Watson, 2020). Other companies, such as *Remilk* in Israel, are yet awaiting regulatory confirmation from their government authorities.

4.4 Potential to scale in India

India has a large total addressable market for Lab-grown dairy, with approximately 996 million people – or nearly 73% of the population – consuming some form of dairy regularly, per the Economic Survey of 2019-2020 (Ministry of Finance, 2021). The dairy industry is also growing and diversifying, with plant-based dairy companies such as *SoFit*, *Goodmylk* and *Nutriva* establishing a retail presence of late. The number of people that have gravitated towards veganism (which supports the consumption of foods not obtained from animals) has also

steadily grown. In addition, roughly 50% of our population is on some form of social media (Keelery, 2021), making scalability and marketing far easier for companies. This makes India an ideal target-market for companies developing lab-grown dairy, as a wide range of people can be targeted. In addition, once lab-grown dairy passes regulation and enters the market, the far more efficient supply-chain will ensure that the investment involved in the production of conventional animal dairy will be cut.

That being said, there are multiple potential factors that may hinder the effective scaling and expansion of lab-grown dairy.

Initially, lab-grown dairy products will not be cost-effective – it will take years to cut costs and increase profit margins. For instance, *Perfect Day* serves 1 pint of their ice-cream for $20 (Starostinetskaya, 2021) – a far cry from the $7.99 per pint served by *Ben & Jerry's*, one of the more expensive conventional dairy ice cream brands (Ben & Jerry's, 2020). Compared to the developed nations where lab-grown dairy has been implemented successfully, India has a far higher poverty rate. Therefore, high costs of lab-grown products may prove to be a financial disincentive to those from lower-income groups, who will not be able to afford lab-based milk on a regular basis. As a result, the initial rollout of lab-grown dairy will only presumably cater to the richer segments of the Indian population, thereby creating a niche that may prove detrimental to profits and financial success for these companies.

Another problem with lab-grown dairy is the huge opportunity cost involved in it - that it will disrupt the huge dairy industry in India, which hires millions of people, uses 300 million bovines and involves 144,000 dairy cooperatives for distribution. Introducing a product that makes the role of animals in dairy production completely redundant has the potential to result in severe structural unemployment and thereby poverty. Moreover, there will be lots of wasted land, labour, capital in the form of factories and equipment, as well as animals. These red flags may discourage legislators and policymakers from supporting the rapid growth and development of the industry.

Another reason the industry may not grow is the threat of scepticism and ethical concerns surrounding genetic engineering. In the past, there has been widespread outcry over the health concerns that altering microbes' and animals' DNA poses to human beings. In addition, while companies claim that their lab-grown dairy components combine to create a product entirely similar in taste and texture to cow milk, there has, barring approvals by the FDA, been little to no evidence to indicate the level of safety of microbial fermentation in the long-term. Further, the advent of social media has created a breeding-ground of misinformation, which could potentially paint a negative picture of lab-grown dairy as opposed to conventional dairy. My survey further revealed various examples of skepticism, which are highlighted in the "consumer sentiment" subsection.

Therefore, while the addressable market for lab-grown dairy is huge in India and has the potential to scale extremely quickly, the costs involved, the threat of disrupting an age-old, firmly established industry, and possible ethical and moral concerns may dissuade regulators and policymakers from endorsing lab-grown dairy in India. However, this does not mean that the industry will never grow and scale in India – the current conventional dairy industry is by no means sustainable, and the prospect of having an industry with substantially lower costs and a more manageable supply-chain makes it more likely for lab-grown dairy to slowly enter the Indian market. Furthermore, to garner traction and increase consumerism for this product, the spread misinformation regarding the process must be prevented by giving people the correct information.

4.5 Plausible future scenarios – "Global Trends affecting Dairy Strategies" (Lund University, 2020)

An 18-month study conducted by the Lund University in Sweden funded by Tetra Pak, called "Global Trends affecting Dairy Strategies", elaborated upon 4 plausible scenarios for the future of dairy, by conducting studies in what they deemed 6 key markets – USA, UK, China, India, Nigeria and Brazil. Each of these 4 scenarios were dependent on the possible socio-environmental forces involved, as well as the level of technological disruption that could take place. Keeping this in mind, the study concluded with the following 4 scenarios, possible by 2030.

1. **Dairy evolution –** Current trends in the dairy industry will continue without much change or disruption, characterized by low technological evolution, low to moderate environmental improvements, and steady growth in the plant-based dairy sector. Conversely, lab-grown dairy remains a marginalized niche and does not see much substantial growth. Therefore, the market shares of each individual sector is as follows: 85% cow-based, 13% plant-based and 2% lab-based dairy.
2. **Green Dairy –** High socio-environmental pressure characterized by policies such as animal-based food taxation, subsidization into plant and lab-based dairy companies and stricter welfare policies. This results in strong plant-based growth, but lab-based dairy takes a hit owing to "unsolved GMO issues." Therefore, the market shares in this high restrictive scenario are: 60% cow-based, 35% plant-based, and 5% lab-based milk.
3. **New Fusion -** Very high technological development, but extremely low environmental improvement. Advanced enhancements in plant-based milk in terms of "nutritional profile and texture" followed by moderate growth; in this scenario all 3 take up a far more substantial market share, with lab-grown dairy seeing high mass-market scalability. Market shares will be: 40% cow-based, 35% lab-grown, and 25%

plant-based dairy.

4. **Brave New Food –** Very high technological and environmental pressure prompts the closure and slowing down of large dairy farms. Lab-grown, fermented milk grows in popularity and thrives, also finding ways to cut costs. This puts lab-based milk at a cost advantage compared to conventional dairy, making it more attractive to consumers. Further, plant-based milk is also helped on by regulatory policies as well as improved technology, including better texture and taste. This complete disruption sees lab-based milk taking 50% of the market share, plant-based milk taking 30% of the market share, and cow-based dairy taking 20%.

While all of these scenarios have been deemed "possible", looking at India's dairy industry landscape, it seems highly likely that this industry will not see substantial growth by 2030. As highlighted in the previous section, issues like structural unemployment, high initial prices, and the rampant spread of misinformation will plague the lab-grown dairy sector in its initial stages. Furthermore, India is seeing the staggered, yet promising growth of the plant-based dairy domain, with companies like *Sofit, Raw Pressery* and *Epigamia* expanding their range of plant-based options. Given that the expected growth of the plant-based dairy sector is likely similar to lab-based dairy, with high initial costs that are expected to reduce, lab-grown dairy alternatives will need to play second fiddle to plant-based dairy until they can undercut prices. Another cause for concern is the regulatory environment in India: mandating a product such as lab-based dairy will, at least, take a few years; even certain plant-based companies have not been given a nod by regulatory agencies. This makes the probability of a "technological transition" quite low, at least from a short to medium-term standpoint (within the next decade). In addition, the demographics of the population that have shown an affinity for alternative dairy products is quite a niche category: 1) a shrinking millennial (25 to 40-year old) population, and 2) high income-group and 3) vegans. This means that a minority of the population is willing and financially able to afford lab-grown dairy at the moment, making the total and serviceable addressable markets for lab-grown dairy low. Hence, even the socio-environmental forces are, at best, medium. Therefore, as the graph depicted in Section 4.5 indicates, India in 2030 firs squarely in the "Dairy Evolution" phase, with animal-based dairy taking 90-95% of the market share, plant-based dairy taking 7-9% of the share, and lab-based dairy taking 1-3% of the market share.

4.6 Consumer sentiment

To adequately gauge consumer attitudes towards lab-grown dairy, I created a survey on the platform *Survey Monkey* that asked respondents whether or not they would be open to consuming lab-grown dairy, paying its comparatively high price, and indicating if they have any ethical/moral concerns. The survey consisted of 40 respondents, all of which were Indians of all age groups. The survey aimed to cover people from different socioeconomic backgrounds as well. The questions asked in the survey are shown in Figure 3.

Limitations:

- *Low sample size*: while 80 people in total filled in the survey (as per July 5, 2021) the platform used for the formulation and analysis of the survey responses, *SurveyMonkey*, only allowed me to see the results for 40 of those responses. As a consequence, the potential sample size for this survey was cut in half.
- *Profile of respondents:* This questionnaire was mainly, barring 1 or 2 exceptions, sent to my family and friends. This could have meant that the responses were skewed towards a more positive stance (i.e., respondents saying "yes" for Question #1 as a result of personal bias). Getting a more randomized population group for the survey would have been more beneficial, as it would completely quell any scope for biases and provide a more holistic range of responses.
- *Fewer people from lower socioeconomic backgrounds*: As mentioned earlier, this survey was only sent to close contacts, a sizeable majority – if not all – of which were from a financially stable background. Therefore, while the survey could adequately address the sentiment of the affluent, it failed to help understand the lower or middle-income class's attitude towards lab-grown milk. Getting this information would be crucial to lab-grown dairy companies looking to penetrate an Indian market where the majority of the population is not financially well-off.
- *Not enough introductory information provided*: As the ethical concerns voiced by some of the respondents will later show, there was evident misinformation. A likely cause of this could have been that my introduction, stated in Figure 1, lacked the intricate details and processes associated with lab-grown dairy. This, in hindsight, could have avoided by requesting the respondents to look at a certain video or webpage detailing the process.

Results

From the 40 that responded to the 5-question survey, 19 (47.50%) said that they would be open to consuming lab-grown dairy, with the remaining 21 (52.50%) stating that they would not. Upon further questioning, a far fewer number of respondents – 4/40 or 10.00% – said that they would be willing to pay 1,500 INR for a 500 ml (around 1 pint) tub of lab-grown ice cream. This shows that cost will be a major disincentive to the purchase of lab-grown dairy products in its initial stages, even among those who are financially well-off. Further, 24 out of

40 respondents, or 60.00% of the sample-size, said that they had ethical concerns regarding the use of lab-grown dairy, citing reasons such as:

"How would we know that they are safe and healthy to the consumer, and what are the side-effects on the body?"

"Quality control in India is not apt. [The] transportation process cannot be trusted."

"Why kill the livelihood of a farmer? Lab grown milk can also be never as good as the natural milk."

"Not sure in what conditions the dairy is being produced…need more details."

"Artificial products can never match natural items."

These concerns contain a range of unfounded beliefs – mainly with regard to the health benefits and taste and quality compared to natural animal dairy – which conveys that in order for lab-grown dairy to scale on a commercial level, potential consumers need to be sensitized to the process and nature of lab-grown dairy. This can be done by using social media platforms to use a vast range of multimedia, such as videos and posters, to show people the real features of lab-grown dairy, and help prevent the spread of misinformation. Even then, as illustrated by some of the more legitimate concerns (with regard to logistical issues and the issue of causing unemployment), it seems that some people will still not be open to consuming lab-grown dairy.

In conclusion, this survey demonstrated that around half of the affluent population would be open to consuming lab-grown dairy. Albeit an assumption, I believe that this value would be much lower if those from a lower-income background were given the survey, as most people are in poor financial situations (and would therefore not be able to afford it) and are more likely to believe misinformation. Moreover, lab-grown dairy companies will need to significantly reduce their costs over a period of time, or else the prevailing sentiment demonstrates that Indians will not be willing to buy their products. Finally, at the heart of people's skepticism is misinformation and a misunderstanding of how the production process works. Therefore, people will be far more likely to accept lab-grown dairy when they realize its benefits compared to natural animal milk.

5. The Market for Alternative Dairy and its Commercial Viability

For the lab-grown dairy industry to gain traction, it is essential that it has a significant competitive advantage compared to the competition, i.e. plant-based dairy. The various benefits of lab-grown dairy compared to conventional cow milk is outlined in the introduction.

5.1 Sustainability

The UN's Food and Agriculture Organization (FAO) reported that around 3% of the world's GHG emissions come from dairy production, as cows and other bovines belch and thereby release large amounts of methane into the atmosphere (FAO, n.d.). Therefore, there is no denying that plant-based milk is far more sustainable than conventional cow milk, with soymilk using ½ as much land and releasing ½ as much carbon emissions (McGivney, 2020). Lab-grown milk, however, is more environmentally-friendly compared to both plant and animal-based milk, as it completely does away with the need of using animals for dairy production. Plant-based milks use land for harvesting various plants, and therefore are quite water intensive – a single glass of almond milk requires 130 pints of water as per a 2018 Oxford Study – and other plants that are insect pollinated put pressure on beekeepers, with a record 50 billion bees dying in 2019's almond farming season (McGivney, 2020). Rice milk, which is readily available on the Indian market, uses large volumes of water and also releases greenhouses gases. Even perhaps the most environmentally-conscious plant-based milk, oat milk, has been reported to use the potentially carcinogenic "Roundup" fertilizer (McGivney, 2020). Moreover, to meet rising global demand, workers are often exploited and rainforests destroyed (McGivney, 2020).

Comparatively, lab-based milk is far more sustainable as it will require a mere fraction of the land (for labs and research centres), water (*Perfect Day* contends they use 98% less water than the average dairy farm) and energy (65% lower as per *Perfect Day*) (Perfect Day, n.d.). Moreover, it mainly requires skilled labour and scientific research, eliminating the scope for physical worker exploitation and deforestation. Lab-grown milk also prevents animal cruelty during dairy production. As a result, it is clear that lab-based milk is the most sustainable milk variation in the market, with a supply-chain that requires a mere fraction of the land and capital required.

5.2 Costs of production

Owing to the fact that lab-grown dairy is not as resource-intensive, it seems the only expenditure required will be for research and development (R & D) as well as marketing and logistics. These costs will initially be exorbitant before a concrete, manageable supply-chain can be implemented, as there will be more investment into developing a fit-for-market product. These costs are still likely to be lower than those of the competition.

Plant-based milks are, in general, more expensive than natural animal milk, with *Amul*'s 500 ml packets costing ₹ 48, and *Sofit*'s 1 litre soya milk costing just over ₹ 123. However, at least in foreign markets, the final pricing of lab-grown dairy, however, is far higher than those of their plant and animal-based counterparts, owing

to the fact that lab-based dairy companies are yet trying to break-even and gain more traction. It can be assumed that the same trend will be seen in India for the next few years after the launch of Lab-grown dairy.

5.3 Consumer sentiment

To better gauge the competitive advantage of lab-grown dairy and why users are more likely to gravitate towards it, it is essential to analyze users' attitudes about the taste of plant-based milks. I analyzed multimedia sources such as videos made by dairy enthusiasts who "taste-tested" plant-based milks and ranked the various types of plant-based milks, as well as prior studies conducted. For instance, Palacio et al. concluded that respondents reported that cow milk was significantly better tasting than soy milk. External influences like ethnicity, age, or gender had no bearing on the results. In a follow-up survey conducted with children and adolescents, similar results were shown. A study with Australian customers also revealed similar results. Analysis of videos revealed a similar picture, with respondents reporting issues such as "bad aftertastes." Oat Milk and Rice Milk emerged the types of plant-based milk that seemed the most acceptable by users, from a taste standpoint.

Aside from taste, the studies by Palacio et al. also revealed that factors such as nutritional benefit and price-point mattered to prospective consumers as well, with social and environmental aspects taking lower precedence. Therefore, given that lab-based milk is possibly the closest to cow milk in taste, nutritional content and texture, and will eventually be cost-effective, users are far more likely to consume lab-grown dairy.

5.4 Conversion into milk products

A major shortcoming of plant-based milks is that most of them cannot be converted into other dairy products, such as yogurt, cheese, and ice-cream. The simple reason behind this is that they essentially lack proteins. Proteins are normally essential in the conversion of milk to milk products, as the lactobacilli bacteria ferment the milk proteins. As a result, thickeners and oils are needed to produce items such as cheese and yogurt, significantly increasing production costs.

The process for lab-based milk, however, is far easier. Given that individual milk proteins can be made in a lab and separated, companies can use those proteins to produce items like ice-creams and cheeses. For example, the company *BraveRobot* uses *Perfect Day*'s lab-based whey protein to produce their ice-creams. This is done by adding certain quantities of whey protein to a vat, adding unsweetened milk at established temperatures and pH levels, and then adding the desired flavour. The final step involved is deep-freezing the mixture to produce lab-based ice-cream.

Companies like *New Culture* have also managed to produce a range of different lab-based cheeses using casein micelles and the process of precision fermentation, highlighted in section 4.2.1. The only difference between the production of lab-based milk and cheese is that cheese is produced at a slightly lower pH level, and makes use of the enzyme rennet, which can also be made in a lab. Yogurt is made in a similar manner as well.

Therefore, while it is not entirely impossible to produce secondary dairy products using plant-based milks, the process is far easier and more sustainable in the long-term with a lab-based scenario.

6. Policy Recommendations for the scalable growth of Lab-grown Dairy

As highlighted in Section 4, the reason why some lab-grown dairy companies are likely to not see wide traction in their initial stages is because of two key issues: a) the large scale and socioeconomic bearing of the animal-based dairy industry on the economy and consequent reluctance from legislators; b) the prevalence of misinformation resulting in distorted consumer attitudes towards lab-based dairy; and c) initial high costs to compensate for high R&D costs and investment liabilities, and establishing a robust and sustainable supply-chain. After analysing these 3 key factors, companies so far can only take concrete measures to achieve b) and c); a) on the other hand is not a reasonable short or even medium-term goal, as established by the analysis in part 4.5, as the concept of lab-based dairy will need substantive legislative backing, especially in what is a strict regulatory landscape. Companies can therefore aim to lobby for the development and backing of their product from the governmental side, but should focus on the following solutions to further expand their user base and gain more market-share.

6.1 – Measures to counter misinformation

As underscored earlier, it is virtually impossible for companies in the lab-based dairy sector to gain any consequential growth until and unless people on a large scale are adequately sensitized to the features of lab-grown dairy, including the process of its production, caveats and benefits for personal health, and its socioeconomic and environmental benefits. This will, to a large extent, get rid of myths such as those expressed in Section 4.6.

- *AI and Machine Learning Approach* – The systematic reduction of misinformation in the lab-based dairy sector can be spurred by the use of artificial intelligence (AI). Concepts of machine and AI can be utilized to identify sources of misinformation on a continuous basis with the aim of achieving:

a) real time evaluation of information posted and propagated on media platforms, such as, for instance, monitoring the most common words associated with the lab-grown dairy company to help pinpoint the main myths associated with lab-grown dairy
b) generating a cohesive database with periodic updates that identifies the core topics and propagators of misinformation to ensure longstanding, permanent solutions
c) the production of an Artificial Intelligence-based (AI) software application specialized for widespread corporate use that employs a set of well-identified criteria that can be utilized by companies to categorize and determine the authenticity of any information sent/received regarding lab-grown dairy;

- *Social Media campaign* – Companies can also leverage their social media presence to counter the spread of misinformation. This could be done quite feasibly, with companies releasing posts and posters conveying, in lucid language, the process, benefits, and safety aspects of their product. Company social media accounts can also further bolster user transparency by conducting open forum sessions with them, allowing customers to interact and ask questions to company managers and scientists; these sessions can be made available for downloading and sharing on public resource domains (for instance the company websites themselves). This will need to be done on a consistent and regular basis, ensuring that the content in question is targeted towards the demographic population that is most likely to spread misinformation.
- *Increasing public involvement* – Companies should also encourage and actively promote the involvement of the people in the aim to increase awareness and curb the spread of misinformation and rumours, with the incorporation of:
  a) incentives provided to consumers to bring theories and instances of misinformation to light and actively try to help prevent its spread; these incentives can include exclusive discounts on certain products or free trials of the product
  b) creation of avenues wherein the public can voice their concerns regarding lab-grown dairy products, to which companies will need to respond respectfully and accurately.

6.2 – "Nudge Marketing" and its implication for online marketplaces

To further boost the number of consumers and bolster popularity, companies can also make use "nudge theory", popularized by Professors Richard Thaler and Cass Sunstein in their prolific and pioneering book "Nudge" (Thaler and Sunstein, 2008). Nudge theory essentially proposes that indirect reinforcement measures which exploit human psychology and behaviour can be utilized to "nudge" people to, for example, purchase certain products, or subconsciously do something that will benefit them and other stakeholders. For instance, putting a basketball net directly above a dustbin subconsciously encourages people to throw their trash, which is better for the environment. Keeping this in mind, companies can focus on expanding traction for their products by applying nudge theory to their marketing strategies:

- *Utilization of product badges* – companies, especially those on online marketplaces, can use "product badges", which are unique identifiers or features that characterize a certain product. These badges could, for instance, denote the scarcity of a certain product ("Only 3 units left!"), any discounts, or even the sustainability of that particular product. Especially within the context and main topic of this research paper, these badges and identifiers are crucial as they have an extremely high propensity to influence consumer behaviours. For instance, the "Noble Edge Effect," proposed by Coglode Research, determined that users were far more likely to buy a product and have their attention and focus drawn to a product which was better for a social cause. This effect could be applied by companies selling lab-grown dairy; they could brand their products as "sustainable" and thereby gain more attention from prospective consumers.
- *Price advertising* – Another extremely effective way to get users to gravitate towards lab-grown dairy would be to propagate the fact that its cost is far lower than that of its animal and plant-based milk alternatives. A caveat to this, however, is that it can solely be implemented in the long-term, after a point where the industry has achieved 'economies of scale' (see Section 3). This can be implemented by making use of a human psychology trait called "anchoring", wherein humans tend to base their decisions of something on prior knowledge. In this case, companies could compare the cost of lab-grown dairy to its other competitors, conveying to users the price benefits of lab-grown dairy.
- *Exit intent overlay with autonomy* – This is generally shown to users if they are about to leave a particular webpage; it asks them questions about whether or not users want to leave the webpage without doing anything, for example adding products to their cart/wishlist or buying the product. While these overlays will likely not succeed 100% of time in eliciting a user response, they will make users think twice before exiting a page. Note that it is important to give the users a sense of autonomy when they are browsing these webpages as psychological research reveals that people want freedom to make

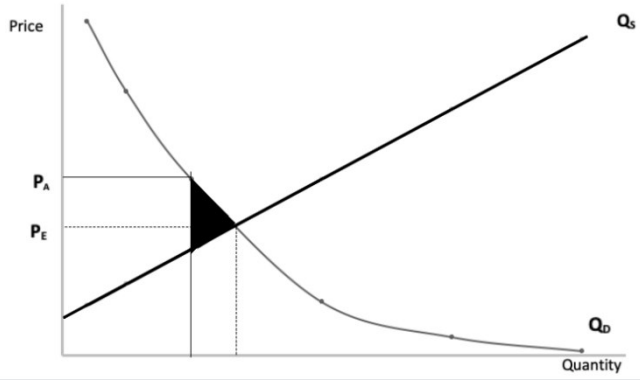
their own decisions (the Hobson's +1 Choice Effect). This autonomy can be giving by providing users with the option to delete the overlay or move to other webpages without any intrusion.

CONCLUSION

To conclude, this paper elaborates upon the economic as well as commercial aspects of lab-grown dairy. A potentially revolutionary food product that could change the sustainability landscape globally, lab-grown dairy, with its highly efficient production method, substantially reduces carbon and GHG emissions, prevents animal cruelty and will one day prove cost-effective to every section of the population, regardless of socioeconomic status. As explained earlier in the paper, its production method will prove significant in cutting costs, and is likely to achieve economies of scale and limit the scope of substantial deadweight losses. That being said, with a high percentage of the Indian population deeply in poverty, 150 million Indians reliant on the animal-based dairy industry for their livelihood, and possible religious and ethical backlash, the rollout and market scalability of lab-based dairy may be hindered in India in the short and medium-term, as explained by our analysis of the "Global Trends affecting Dairy Strategies" framework in Section 4.6. Companies therefore need to ensure that to bring this revolutionary product to market effectively, people need to be given the chance to understand the caveats and features of lab-grown dairy. Only then will this industry grow harmoniously and prosperously – and, more importantly, build a far more sustainable world.

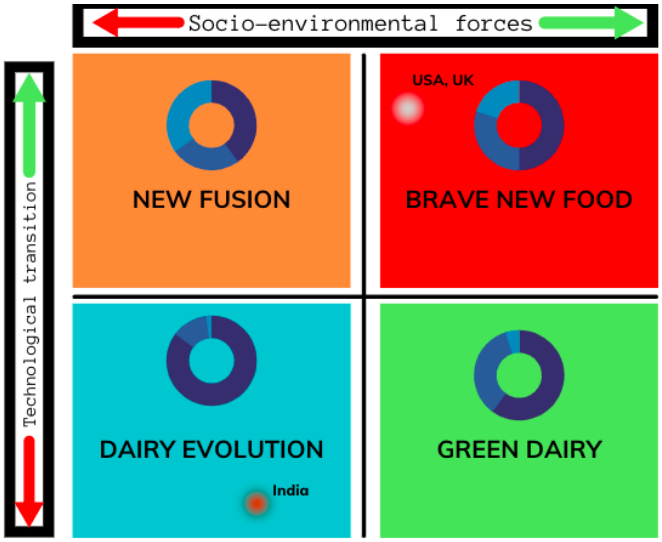
APPENDIX

Figure 1



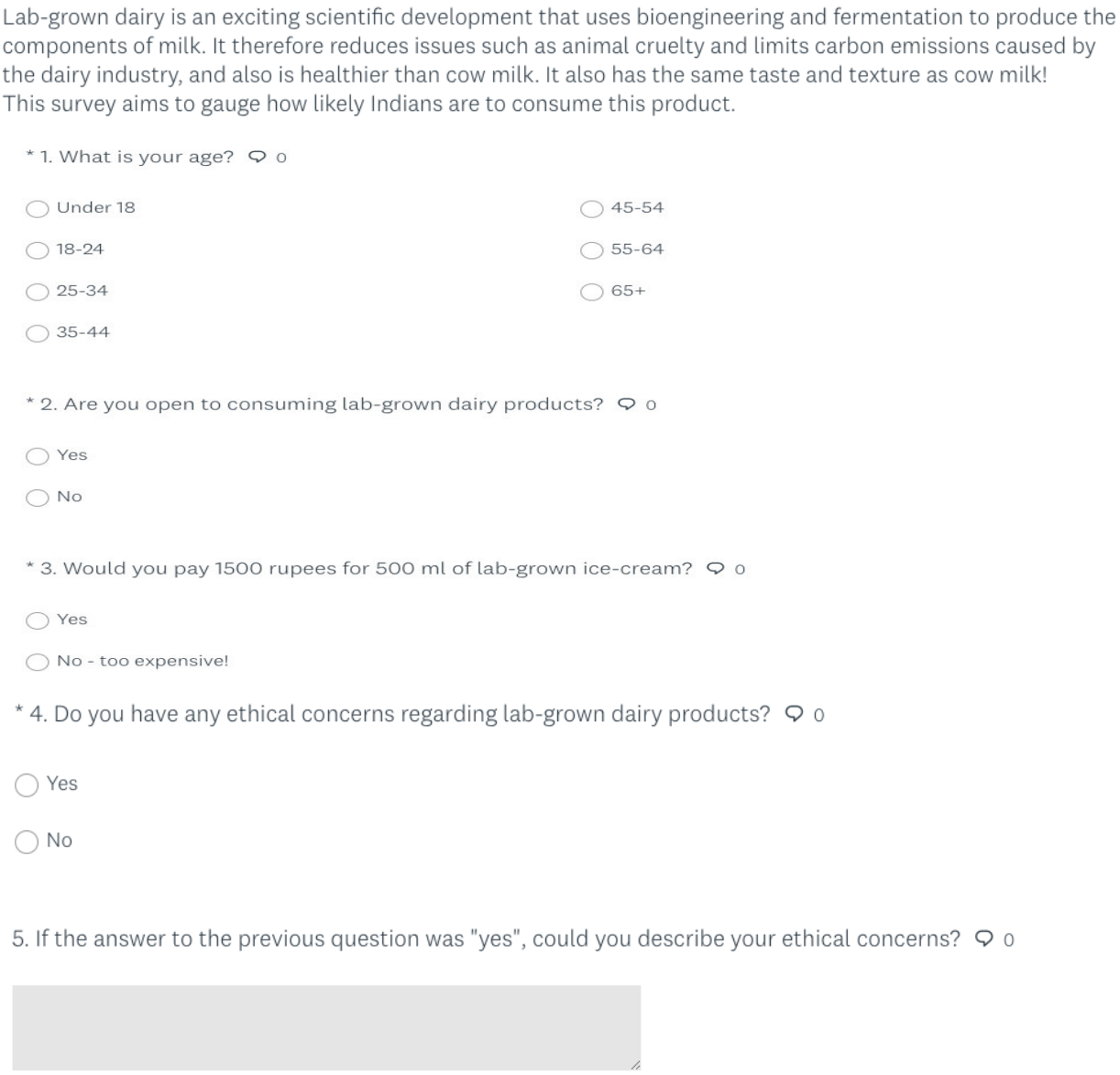
Supply-demand curve; black shaded region represents Deadweight Losses as a consequence of price-hikes in the animal-based dairy sector. Produced by the author.

Figure 2



Graph for 'Global Trends affecting dairy strategies." Adapted from* "Tetra Pak Studies the Future of Dairy."** ***Dairy Industries International**, 30 Sept. 2020.** ***Recreated by author with reference to the current competitive positions of India, the USA and UK.***

Figure 3



Preliminary survey questionnaire to determine the commercial viability of lab-based milk. Produced by authors.

Table 1

#	Company	Country	Technology used	Product(s)	Investment/USD, approx. # of employees	Market presence
1	Perfect Day	USA	Microbial fermentation of *trichoderma*	Milk whey powder	361.50 million, 92-100	Yes; outsourced to third-party companies such as *Brave Robot* for further production of secondary dairy products.
2	Remilk	Israel	Microbial fermentation; the company has not revealed its ingredients as it awaits patent protection	Milk	11.30 million, 31-50	No; the company yet awaits patent protection and crossing regulatory barriers.
3	New Culture	USA	Precision fermentation; microbial fermentation to produce casein using the enzyme *chymosin*	Mozzarella cheese	5.10 million, 10-20	No; yet to hit the American market but has waitlists for upcoming tasting trials.
4	TurtleTree Labs	Singapore, USA	Cell-based technology; extraction of mammary cells, added to nutrient solution that mimics that of mammals' bodies. Cells can be reused.	Human milk powder called "lactoferrin"	9.40 million, 27-30	No; expected rollout and commercial scalability in a few years owing to regulatory policies.
5	Better Dairy	England	Yeast fermentation in "large vats" through a process similar of beer production	Dairy proteins	2.34 million, 1-10	No; still in the production and R&D phase.

Overview of the lab-based dairy competition worldwide. Produced by the authors.

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