The Societal and Environmental Impacts of the Skincare Industry: A Case for Innovation

by

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SUBMITTED TO THE INTEGRATED DESIGN AND MANAGEMENT PROGRAM
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Abstract

The $17 billion U.S. skincare industry negatively impacts women's health. It sets unrealistic beauty standards and ideals that are meant to influence consumers' product choices. Skincare products are unevenly regulated, and many formulations contain chemicals that harm individuals' health and end up in toxic landfills and watersheds. Skincare companies offer products with ingredients that are not verified or tested for safety or efficacy. Additionally, skincare products have historically been created for fictional archetypes, and insufficient attention has been paid to consumer's unique and changing skin needs. The short-term and long-term health outcomes resulting from skincare product usage affect divergent populations differently, due to the behavioral differences between women of different ages, ethnicities, and geographic locations, as well as other demographic and psychographic factors. This thesis examines these factors and looks beneath the skin of the industry, challenging the current modus operandi of its players.

Using data mining techniques, the correlation between these factors are identified and used to predict skincare product waste. Unsupervised learning is used to group skincare consumers by their consumption behavior, as opposed to their demographics. A diverse sample of skincare consumers was chosen to score the skincare products in their everyday routine with both an individual health and environmental safety score. One solution supported by the research is innovation and new companies that are focused on customer education, ingredient transparency, and the measurement of individual safety outcomes resulting from skincare product usage.

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Introduction

HISTORY OF INDUSTRY

The earliest extant documentation of a skincare product dates to 2800 BC: a Babylonian clay tablet listing the formulation of a soap containing water, alkali, and oil.[1] Several thousands of years later, soaps became one of the first skincare products to be mass manufactured. The evolution of synthetic detergents (surfactants) in the 1940's and 1950's led to product formulation opportunities by combining oil-soluble materials with water-soluble materials. Through much of the 20th century, skincare preparations were primarily moisturizers and emollients. From the 1970's through today, technology has advanced the development of active ingredients to enhance the skin's appearance. These materials include: alpha and beta hydroxy acids, retinol derivatives, vitamin derivatives, advanced bioengineered ingredients which aim to stimulate collagen, ingredients which limit protein enzyme activity, natural moisturizing factors and even human fibroblast conditioned media.[2] Technology continues to become more sophisticated as it evolves both within major manufacturers of skincare products as well as within the suppliers who develop base ingredients for these manufacturers.

Concurrently, the rise of green or environmentally sustainable products has become a dominant industry trend. The 1980s saw the rise of eco-labeling and in the last 10 years, there has been increased attention towards the rising level of consumption, including personal care products

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[1] *Introduction to Surface Tension,* Non-Newtonian Fluid Dynamics Research Group, web.mit.edu/nnf/education/wettability/intro.html.
[2] *Process for Formulating a Custom Skincare Product*, US7349857 (United States Patent and Trademark Office, April 9, 2003).

such as skincare. The market for green and clean beauty brands is growing exponentially on a global level, between 8-10% each year, which is related to the rise of social pressures.[3]

Dermal biometrics (sometimes called bioengineering techniques) have significantly improved over the last decade. Measurement of skin properties and function became critical in supporting representations for products placed in the mass retail trade. Representations like "improves fine lines and wrinkles", "improves skin firmness by x %", etc. have been commonplace in the market today. These representations are made through the analysis of large groups of panelist volunteers who allow themselves to be measured using biometric techniques along with experimental skincare products. The types of skin properties that are tested include moisturization, firmness, elasticity, sebum amount, skin thickness, skin profilometry, trans-epidermal water loss (barrier function), and photographic analysis (visible and UV to determine photo damage).

THE INDUSTRY TODAY

The skincare industry is a huge economic force; its market is estimated to be worth about $400 billion globally. The United States skincare market alone has a value of nearly $17 billion and a compound annual growth rate (CAGR) of 1.8%.[4] In 2017, the skincare market grew much faster than recent years due to an increased emphasis on personal health, rising individual spending power, and widening global distribution of ingredient manufacturers and suppliers. Facial skincare products make up the largest segment; 75% of the market's overall value in 2017.[5]

The United States' economic recovery from 2012-2016 has supported consumer purchasing power in the skincare industry, especially with the high disposable income of the baby-boomer

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[3] *Skincare Industry Profile: the United States,* (Business Source Complete: Dec. 2017), 1–40.
[4] Ibid.
[5] Ibid.

generation. Historically, large legacy brands have dominated the industry in market share and prestige. However, the rise of millennial and Gen X consumers has spurred the introduction of digital-born brands, quickly becoming the largest growth category, claiming more than 70% of the $2.7 billion VC investments made between 2014 to 2017.[6] E-commerce has allowed skincare companies to expand their consumer base and enhance product distribution on a global scale. Marketing has shifted as a result of this digital boom; social media "influencer" marketing has rapidly become one of the most popular ways younger consumers discover skincare brands, access product reviews, and receive skincare advice.

CURRENT TRENDS

The primary drivers of growth for the skincare market[7] are the aging population, technological developments, social commerce, and an increased awareness surrounding health and wellness. The "clean" and wellness-focused boom is part of a larger movement across food, fitness and medicine that e-commerce agency One Rockwell calls the "Market of Prevention." The Market of Prevention is defined by "a total, holistic, inside/outside, whole-person state of balanced wellness" in the prevention of disease.[8] The emphasis on prevention is reflected in top reported skin concerns; US consumers are increasingly concerned with aging, which is driving demand for innovative products focused on wrinkle reduction and prevention. Even young adults are opting for products with preventative or anti-aging benefits.[9]

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[6] Sarah Hudson et al, *What Beauty Players Can Teach the Consumer Sector about Digital Disruption*, (McKinsey: Apr. 2018).
[7] BSC Skincare Industry Profile 2017.
[8] *Hitting a Moving Target: Why Attracting Evolving Beauty Consumers Is Harder Than You Think*, Shopify, www.shopify.com/enterprise/hitting-a-moving-target-why-attracting-evolving-beauty-consumers-is-harder-than-you-think.
[9] BSC Skincare Industry Profile 2017.

Premium anti-agers are among the market's strongest growth categories, and become diversified with the incorporation of additional benefits such as UV protection.[10] As skincare is becoming a highly saturated market and consumers look for multi-functional products, personalized and customized formulations are becoming more popular. Technology and digital development have aided the focus on personalization in beauty; moving towards "suitable for me" to "made for me" customization. This is achieved through better product matching, custom formulations, and smart devices and applications aimed to help customers choose the right product for them.

As consumer preferences continue to change, the "clean beauty" movement is solidifying itself as a permanent category within the skincare industry. "Clean beauty" is defined differently by various groups, but a common definition is: personal care products that are free from ingredients that have been suspected or proven to have personal health and safety concerns. The clean beauty movement has a tendency towards promoting formulations with organic and all-natural ingredients over those with chemical ingredients. The skincare industry is following the conscious-consumption movement seen in food and agriculture with consumers paying more attention to the sourcing and quality of ingredients in their skincare products.

The limitations of mass market skin care products has led to explosive growth in Do-It-Yourself ("DIY") skincare. Today, many bloggers and social media influencers recommend their personal skin care regimes and recipes. According to research by Google, the overall DIY category (including terms "DIY," "homemade," and "how to") in the U.S. is growing at 8%.[11] Searches that specifically include the term "DIY" are growing by 38%.[12] Customers are eager to take skincare

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[10] BSC Skincare Industry Profile 2017.
[11] *Beauty Trends 2017: Skin Care Edition* Think with Google (Google: 2017).
[12] Google Beauty Trends 2017.

into their own hands – as a result of the clean beauty movement, they want to understand what specific ingredients work for their skin and how to create simple, natural products on their own.

SKINCARE RETAIL

The United States is suffering from a crippling decline in retail overall, with major retailers in related industries, such as fashion, closing their doors. Beauty-focused retail, however, keeps growing, as an experiential component of many digitally-native brands that have focused on creating an experience across channels. According to the Coresight Research group, beauty specialist stores (including Ulta and Sephora) grew their total market share from 12.0% to 14.3% between 2011 and 2016. Internet retailing's market share grew from 5.6% to 8.4% over the same period- including beauty and personal care e-commerce sales by all retailers (not just beauty-specific).[13] Digitally-influenced customers tend to spend more on skincare products since they have more extensive skincare routines, using 8-14 skincare products weekly.[14]

The popularity of curated online beauty marketplaces and direct-to-consumer brands has made indie skincare labels more accessible than ever. The last 5 years have shown a steady rise in the number of digitally-savvy indie skincare brands entering the market with niche-focuses. These indie brands are reaching customers that traditional beauty companies have ignored, such as color cosmetics for previously under-served complexions or men's skincare. The combination of e-commerce and a focus on inclusivity and diversity in the industry has led to significant product innovation. Indie brands are often able to innovate more quickly than incumbent players; which has led to a great amount of acquisition. According to Coresight,

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[13] *Deep Dive: Channel Shifts in US Beauty Retailing-Sephora, Ulta and Amazon Carving Greater Share*, Coresight Research,www.fungglobalretailtech.com/research/deep-dive-channel-shifts-us-beauty-retailing-sephora-ulta-amazon-carving-greater-share/.

[14] Amanda Hartzmark, *Premium Opportunities: US Market Trends and The Changing Consumer Landscape*, (Euromonitor International: Sept 2016).

there has been a major increase in merger and acquisition activity in the beauty industry in the last 3 years- 91 deals in 2016, up 25% from deals made in 2013. Global brands are focusing on acquisition, rather than rapid product development, as a key strategy to drive growth and enter new markets.

INGREDIENTS AND SAFETY

The potential dangers associated with the use of synthetic chemicals absorbed by the skin has increased consumer demand for safer and healthier alternative products and driven interest in product quality and safety issues.[15] Consumers are beginning to pay more attention to irritants and what comes in contact with their skin, leading to new rise of products free from parabens, aluminum, and alcohol among other ingredients.

Skincare products often contain multiple chemicals, such as formaldehyde, phthalates, lead, mercury, triclosan and benzophenone that can adversely impact health. Exposure to more than one of these chemicals has been linked to endocrine disruption, cancer, reproductive harm, and impaired neurological development in children.[16] Women who are heavy skincare consumers (defined as buying more than 10 products per year), usually between the ages of 18-34, and their offspring, are particularly vulnerable to toxic environmental chemicals if they are using the products during vunerable times such as preconception or pregnancy.[17] For example, during pregnancy a fetus absorbs an even greater amount of chemicals than the mother herself does.

The rise of digital commerce and social media as a significant channel of marketing has driven product safety education and led to the billion-dollar clean beauty movement, estimated to grow

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[15] Ami R. Zota and Bhavna Shamasunder, *The Environmental Injustice of Beauty: Framing Chemical Exposures from Beauty Products as a Health Disparities Concern* (American Journal of Obstetrics and Gynecology: 2017), vol. 217, no. 4.
[16] Ibid.
[17] Ibid.

to a staggering $13.2 billion this year.[18] Brands with a natural and/or botanically- derived clinical orientation now represent the largest combined share of prestige skincare sales. Last year, they accounted for all gains in the category. Consumers are demanding safer choices and better manufacturing practices, making health and wellness a priority in their lifestyle and the brands they support. As a result, skincare consumers are making more value-based purchases, manifesting in a growing popularity of organic and natural products.

A global study done by European Monitor found that "green" features remain one of the top five traits that consumers look for in beauty products, before even brand names. In the skincare category, green product features, including "natural or organic" and "environmentally-friendly or ethical" rest among the top five features sought by digital consumers in 2015 and 2016.[19] Many consumers are willing to pay a premium for products they believe to be safer for them. A study by Nielsen reported that 46% of consumers are willing to pay more for organic skincare products.[20]

However, clean and/or organic ingredients themselves are not necessarily enough to deem a skincare product safe. "Organic" skincare ingredient claims are not regulated or enforced by the Food and Drug Administration (FDA) or US Department of Agriculture (USDA). Skincare companies can loosely claim "organic" for the process of extracting ingredients from organic produce- sometimes the "organic" extraction is done using chemical methods. Dosage amount is also critical when understanding the potential toxicity of an ingredient. Even natural

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[18] Rina Raphael, *What's Driving The Billion-Dollar Natural Beauty Movement?* (Fast Company: 15 Oct. 2017), www.fastcompany.com/3068710/whats-driving-the-billion-dollar-natural-beauty-movement.
[19] *Beauty Survey 2016: Key Insights and System Update* (Euromonitor International: Oct 2016).
[20] James Russo, *Package This: Beauty Consumers Favor 'Cruelty Free' and 'Natural' Product Claims* (The Nielsen Company).

ingredients can be harmful at overly concentrated amounts.[21] Some natural ingredients should never even appear in cosmetic formulations because they are not safe for skin contact. The FDA warns against potential contamination for natural skincare products, stating: *"Consumers should not necessarily assume that an 'organic' or 'natural' ingredient or product would possess greater inherent safety than another chemically identical version of the same ingredient. In fact, 'natural' ingredients may be harder to preserve against… contamination and growth than synthetic versions."* [22]

Because of the lack of required safety testing in the US skincare industry, many smaller beauty brands do not have extensive testing protocol in place. These companies can sell skincare products directly to consumers without completing rigorous safety testing, such as a toxicology profile or "patch testing" for cosmetic allergens, which is considered to be the gold standard by dermatologists. Looking toward regional markets with more rigorous safety protocols, a comprehensive safety assessment is required for all cosmetic products sold in the EU, including allergy testing and a declaration of manufacturing practices.[23] Overall, there is no cohesive definition or comprehensive safety standards for the US skincare industry, leading to customer confusion in navigating organic and natural product offerings.

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[21] Ursula Klaschka, *Natural Personal Care Products Analysis of Ingredient Lists and Legal Situation*, (Environmental Sciences Europe: 2016), vol. 28, no. 1.
[22] Natasha Singer, *Natural, Organic Beauty* (New York Times: 1 Nov. 2007), www.nytimes.com/2007/11/01/fashion/01skin.html
[23] *Safe by Design* (Cosmetics Europe-The Personal Care Association), www.cosmeticseurope.eu/cosmetic-products/safe-design/.

Existing Problems in the Skincare Industry

BUYER POWER

The main players in skincare product development and distribution have created a standard business model built on pushing new products into the market. Hypermarkets and supermarkets distribute the largest share of skincare products in the United States- 23.1% of all total sales of skincare products in 2016. Health and beauty stores represent 21.1%.[24] The main players in the US skincare industry, including L'Oreal, Estee Lauder, Johnson and Johnson, and Unilever (who together account for 40% of the market) invest a significant amount of money in the R&D of new products, specifically those in emerging economies. In 2017, Estee Lauder spent $179 million[25], or 1.5% of their total revenue, on research and development. Manufacturers drive demand and increase brand loyalty, pressuring retailers into stocking certain products and weakening "buyer power".[26] Buyer power refers to a method of analyzing a business's competitive landscape that was developed by Michael Porter. It is defined as being the power of the consumer to place pressure on a company to ask them for higher quality products, better customer service, and competitive prices.

Instead of starting with the consumer need in product development, big skincare brands focus on the latest "it" ingredient. These brands put an exorbitant amount of money towards marketing, making consumers fit a fictional archetype that may not accurately represent their specific skin's needs. The resulting lack of product diversification perpetuates the larger social

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[24] BSC Skincare Industry Profile 2017.
[25] *R&D Expenditure of Estée Lauder Worldwide 2015-2017* (Statista), www.statista.com/statistics/609083/randd-expenditure-of-estee-lauder-worldwide/.
[26] *The Five Forces* (Harvard Business School: Institute for Strategy & Competitiveness), https://www.isc.hbs.edu/strategy/business-strategy/Pages/the-five-forces.aspx.

and cultural problems of consumer diversity and buyer power in the industry. This occurs because hypermarkets and supermarkets sell similar products developed and marketed towards a similar type of consumer. In order for *all* consumers to have access for safe and effective skincare products, their buyer power needs to increase.

LACK OF CONSUMER EDUCATION

There is a vast amount of skincare content and education available on the internet, however, it's hard for consumers to find reliable and accurate content that is directly related to their skin needs. The disconnect for most consumers stems from a lack of knowledge about their own skin and skin type. Less than 10% of US consumers have seen a dermatologist to help diagnosis their skin and educate them about how to solve their skin concerns.[27] This means that the majority of consumers are choosing their own products by self-diagnosing their skin type and if motivated, researching a product's active ingredients.

At the same time, skin disorders are becoming more prevalent, including acne, eczema and contact dermatitis. A report by the NPD Group reports more women perceive their skin as sensitive today as opposed to two years ago (up to 48% from 44%).[28] The same report concluded that ingredients are the main purchasing determinant for products. While it is important for consumers to know what ingredients to use, it is equally as important for them to know what ingredients to avoid. For women with sensitive skin, generic advice from beauty magazines and blogs is to avoid irritants like "fragrance;" however, there is a nebulous meaning

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[27] *Medical Specialists: People Who Used a Skin Doctor (Dermatologist) in the U.S. 2017* (Statista), www.statista.com/statistics/228530/people-who-used-a-skin-doctor-dermatologist-usa/.
[28] *Women's Facial Skincare Consumer Report 2017* (The NPD Group, Inc).

to what "fragrance" entails and how to identify it in products, as the definition can broadly include even natural irritants such as essential oils.[29]

The 2017 Google Beauty Trends Report showed that "ingredient" searches were a cross-market theme, as well as searching product category and ingredients together or skin concerns and ingredients together. It's evident that consumers are seeking out information about the product but what's missing is knowledge about their skin, especially if they have not been to a dermatologist. For consumers, the most difficult part of purchasing a new skincare product is knowing if it will work for their skin.[30] While it's impossible to predict exactly how skin will react to an new product, consumers could make better and safer choices if they had a basic understanding of their skin attributes. Knowing how to map their skin needs to the most effective and safe ingredients for them would minimize the occurrence of bad product reactions.

OVERSATURATION OF PRODUCT OFFERINGS

Although users are becoming more selective about the ingredients in their products, they are also expanding their product routines. Over one-fifth of women today are using 5 or more skincare products as part of their daily routine.[31] The Environmental Working Group estimates that women use an average of 9 beauty products (to include skincare and other cosmetics) per day, which would expose them an average of 126 different chemicals.[32]

Consumers find it difficult to choose products because they don't understand what their skin needs and because there are so many options to choose from. There are hundreds of

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[29] Kari Molvar, *Skin Care's Backlash Against Essential Oils (*The New York Times: Sept. 29, 2017), www.nytimes.com/2017/09/29/t-magazine/skin-care-essential-oils-backlash.html.
[30] Meghan Maupin, *Skincare Habits and Routines*, Survey (Qualtrics: February 2018).
[31] NPD Group Facial Skincare Consumer Report.
[32] Kyla W Taylor et al., *Associations among Personal Care Product Use Patterns and Exogenous Hormone Use in the NIEHS Sister Study* (Journal of Exposure Science and Environmental Epidemiology: 2017), vol. 27, no. 5, 458–464.

thousands of unique skincare products currently on the market, with large beauty retailers like Ulta offering around 500 different brands in store.[33] A study by Mintil showed 65% of female beauty consumers find the number of options when shopping for products overwhelming.[34] Additionally, women are subjected to over 5,000 brand messages per day,[35] leading to decision fatigue and white noise. Overwhelmed consumers turn to their trusted sources, family and friends, to get suggestions for products.

A quarter of millennials also discover new products through beauty blogs and social platforms like Instagram.[36] The problem with influencer-driven discovery is that the skin attributes of the influencer may be different than the consumer, often leading to unsatisfactory results. Furthermore, influencers are usually paid by brands to recommend their products, and may not even actually use them personally. The oversaturation of product offerings combined with a lack of individual skin knowledge about their unique skin attributes creates waste and confusion. The result is a trial-and-error process where women, on average, throw away over $100,000 of unused products in their lifetime.[37]

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[33] Jessica Tyler, *We Shopped at Sephora and Ulta to See Which Was a Better Beauty Store - and the Winner Was Clear* (Business Insider: May 8, 2018), www.businessinsider.com/sephora-vs-ulta-sales-compared-photos-details-2018-4.

[34] *The Beauty Consumer US Report 2016* (Mintel), http://www.mintel.com/press-centre/beauty-and-personal-care/7-in-10-us-female-beauty-consumers-say-its-important-to-look-their-best-when-leaving-the-house.

[35] Louise Story, *Anywhere the Eye Can See, It's Likely to See an Ad* (The New York Times: Jan. 15, 2007), www.nytimes.com/2007/01/15/business/media/15everywhere.html

[36] Mintel Beauty Report 2016.

[37] Bianca London, *Women waste £180,000 on unused beauty products in a lifetime* (Daily Mail Online: May 15, 2014),www.dailymail.co.uk/femail/article-2629129/Women-waste-180-000-unused-beauty-products-lifetime-men-prefer-natural-look.htm.

EFFICACY BIAS

Several problems arise when formulating skin care products for the mass market. When products are formulated to accommodate the largest possible group, the resulting claims are generic and misleading. What occurs is a proliferation of skin "type" products in the market. Types include: oily, dry, combination, acne prone, sun sensitive, sensitive skin, allergy tested, poor texture, large pores, etc. Manufacturers must strike a balance between what is economically feasible for them relative to the quantity of products available in the market and the amount of customers they can attract from the market.[38]

Further adding to efficacy bias is the way that products typically go to market; skincare companies that fall into the Cosmetic category are not required to do clinical trials and therefore do not always know the effectiveness of their product before it becomes available to consumers. If clinical trials are done; there are no requirements for the diversity of users in terms of qualifications such as ethnicity, age, or particular skin attributes. Selection bias is so common to clinical trials for drugs and medical treatments that many research papers have been dedicated towards suggesting alternative techniques to reduce bias;[39] many of these techniques could also be applied to skincare testing such as including randomization to make the selected trial population reflect the diversity of the real world population.

The result is biased trial outcomes and unregulated claims such as "99% of users saw a reduction in red spots" when there might only be a narrow subset of an already-limited number of users tested in order to achieve those results. In order to make products that are truly safe,

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[38] US Patent 7349857

[39] Oleksandr Sverdlov and William F Rosenberger, *Randomization in Clinical Trials: Can We Eliminate Bias?* (Clinical Investigation: 2013), vol. 3, no. 1, 37–47.

more rigorous and diverse clinical trials and testing are needed. The focus needs to shift from marketing and selling a generic product to a large undifferentiated market of consumers, to measuring the results of how the products work and which groups of consumers they are actually most effective for.

REGULATION AND TESTING

As defined by the FDA, there are two categories that skincare products fall into: 1) cosmetic or 2) drug. Skincare that is considered to be cosmetic is sold over the counter and the Federal Food and Drug Administration (FDA) mainly regulates product labeling and warnings. Unlike drugs and other devices used for medical treatment, Congress has not required cosmetic manufacturers to obtain premarket approval for a new product. In fact, according to the Office of Cosmetics and Colors at the FDA, *"a cosmetic manufacturer may use almost any raw material as a cosmetic ingredient and market the product without an approval from the FDA"*.[40] The FDA currently bans only 30 ingredients from being used in skincare products, while the EU bans over 1,400 and Canada over 800.

FDA oversight on cosmetics is reactive, not preventative. Their oversight includes any investigation due to "probable cause" after the cosmetic product has already been released on the market. Without a legal requirement for cosmetic companies to collect reports or report adverse effects or register marketed products, the FDA must wait for clues from voluntary reports suggesting a product isn't as safe a presumed.[41] Adverse events are reported voluntarily by consumers to either the FDA or product manufacturers, who are not required to pass along the information to government. The FDA is not authorized to recall products that are harmful, or require warning labels for potential groups at risk, such as children.

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[40] FDA, 2016b.
[41] FDA, Federal Food, Drug and Cosmetic Act, Section 801(a).

Other agencies involved in skincare regulation include the Federal Trade Commission, who monitors claims made by skincare product advertisements. However, there remains a lack of required testing and independent researchers testing the validity of claims made by the product manufacturers. Cosmetic products may be subject to state laws that impact labeling, packaging, and marketing (such as California's Proposition 65 that requires labeling of listed chemicals that cause cancer and birth defects).[42]

Because the federal government does not play a major role in regulating the ingredients that go into over-the-counter skincare products, the industry relies on primarily self-regulation. According to the FDA website, "*Companies and individuals who manufacture or market cosmetics have a legal responsibility to ensure the safety of their products. Neither the law nor FDA regulations require specific tests to demonstrate the safety of individual products or ingredients. The law also does not require cosmetic companies to share their safety information with FDA*." Many manufacturers adhere to industry standards, codes, and guidelines for quality and safety that are supported by the Personal Care Products Council, the industry's major US trade association. The industry has initiated voluntary efforts through the Cosmetic Ingredient Review Expert Panel, which is industry-funded and cannot be considered an entirely independent source. The current panel also does not directly represent the population of skincare consumers- with only one voting panel member who is a female, out of 12. In the last 50 years, the CIR has found only 11 chemicals unsafe for consumer use.

[42] California Environmental Protection Agency. Office of Environmental Health Hazard Assessment, California, Proposition 65 program.

In May of 2017, Senator Dianne Feinstein of California proposed the "Personal Care Bill" [43] as an amendment to the Federal Food, Drug, and Cosmetic Act to ensure the safety of cosmetics. The FDA Cosmetic Act has not been updated since 1938, with Senator Feinstein calling the lack of oversight into the cosmetics industry a "broad threat to public health."[44] This new bill would require the FDA to review at least five classes of chemicals each year and look at the cumulative and aggregate exposure to ingredients as part of the analysis when available. The act would also require manufacturers to disclose the ingredients they use and register with the FDA annually. Under current law, the FDA lacks the authority to review the ingredients in personal care products to determine whether they are safe and in what amounts they should occur in product formulations.

WASTE AND PACKAGING

The beauty industry at large generates a significant amount of both chemical waste and plastic waste from packaging. According to the Environmental Protection Agency, packaging accounts for 30% – or 75.2m tons – of total solid waste generated yearly.[45] Since cosmetic products are consumables, women are consistently buying cosmetic products that normally come in several layers of plastic packaging. Although alternative packaging designs have been proposed, zero-waste packaging is not mainstream in the industry. Instead, packaging is seen as an aesthetic brand statement driven by its shareability, where zero-waste takes the back seat to experience-driven marketing.

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[43] *S. 1113 — 115th Congress: Personal Care Products Safety Act* (GovTrack.us: Apr. 29, 2018), https://www.govtrack.us/congress/bills/115/s1113.
[44] *Viewpoint: The Personal Care Products Safety Act - JAMA Internal Medicine* (United States Senator for California), www.feinstein.senate.gov/public/index.cfm/op-eds?ID=CFFA2261-11AE-4A11-A3BA-971B514BA40B.
[45] *Advancing Sustainable Materials Management: Facts and Figures* (Environmental Protection Agency).

The skincare industry's impact on the environment isn't only affected by packaging. Its environmental impact includes the farming of skincare ingredients, manufacturing of both the products and their packaging, use of packaging during shipping, product use (when it inevitably washes down the sink), and product end-of-life disposal. The high turnover of products from a consumer's lifelong trial-and-error process of finding the right product only further amplifies this impact.

The solution for cosmetic packaging is complex, but over half of millennial consumers are willing to pay extra for sustainable packaging.[46] A zero waste solution must address the challenges of working with skincare retailers, many of whom require certain packaging to ensure that products are shipped efficiently and arrive to the customer undamaged. Skincare products are hard to separate for recycling at the end of life and have high collection and processing costs. Refillable packaging poses its own problems with time constraints, logistics, the availability of refills and mobility required by the consumers. Zero waste packaging will require a major shift in industry standards, but already Unilever and L'Oreal have pledged to have 100% reusable, recyclable or compostable packaging by 2025.

Understanding the lifecycle of water in skincare product manufacturing and use exemplifies the cascading environmental impact of the industry. Many skincare products are energy-intensive to produce and water is a main ingredient in many skincare formulations. Large amounts of water are required to create the chemicals used in skincare formulations and to deal with the chemical

[46] *Investing in the Future: Millenials are Willing to Pay Extra for a Good Cause* (The Nielsen Company: June 23, 2014).

waste as a by-product of manufacturing. Plastic packaging also requires significant water to manufacture and if not recycled like most of bathroom waste, ends up in landfills.[47]

In addition to packaging waste, chemical waste produced from skincare manufacturing and product use is polluting waterways and destroying marine life. Some skincare products have ingredients that are biologically active and are characterized by persistence and bioaccumulation potential, posing a long-term threat to water ecosystems and human health. Moreover, sewage treatments are not effective at removing some chemicals used in skincare formulations, including: musk (fragrance), perfluoroalkyls compounds, organic UV-filters, microplastics and others.[48] These chemicals can accumulate in the wastewater sludge that is used as a fertilizer on crops. Chemicals from skincare products have been found in streams, rivers, lakes, oceans and even agricultural soil. On May 1, 2018, Hawaii became the first US state to ban sunscreens containing oxybenzone and octinoxate, two chemicals shown to harm coral reefs.[49]

Skincare products pose more pressing ecological problems compared to pharmaceuticals, because they are used in larger quantities throughout the consumer's life and are not subject to any metabolic changes, entering the larger ecosystem in their original chemical form. Skincare products should be subject to a full life-cycle analysis (LCA) in order to assess the environmental impact at each stage of a product's life, from raw material extraction to disposal. Showing commitment to reducing their environmental footprint, L'Oreal worked with

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[47] Cherry Wilson, *Should You Have Two Bins in Your Bathroom?* (BBC News: Feb. 3, 2017), www.bbc.com/news/uk-38856081.
[48] Claudia Juliano and Giovanni Antonio Magrini, *Cosmetic Ingredients as Emerging Pollutants of Environmental and Health Concern (*Cosmetics Journal: 2017), Volume 4, Issue 2.
[49] Elaine Glusac, *Hawaii Passes Bill Banning Sunscreen that Can Harm Coral Reefs* (The New York Times: May 3, 2018), https://www.nytimes.com/2018/05/03/travel/hawaii-sunscreen-ban.html.

environmental sustainability consulting firm Quantis in 2017 to develop the SPOT (sustainable product optimization tool) which assesses the environmental impact of their various products. In order to achieve sustainable progress across the industry, more transparency is needed to make it easy for both consumers and skincare brands to measure the impact of their products.

Thesis Research Objectives

The objective of this thesis is to better understand the societal and environmental impacts of the skincare industry through examining the following:

1. Understanding Consumer Behavior Leading to Skincare Product Waste

Identify the largest predictors of skincare product waste by looking at the behavior of skincare consumers by their age, ethnicity, geographic location, skin allergies, skincare ingredient knowledge, and product spend. Understand the variables that lead to buying and discarding unused skincare products to inform sustainable strategies aligned with consumer decision-making.

2. Measuring the Environmental Impact of Consumer's Skincare Products

Apply the EU's REACH protocol to measure the environmental safety of the skincare products in five women's everyday routines. For each product, the environmental safety score is measured according to its environmental fate and effect on environmental organisms. This score is compared to the EWG's human health safety score and the consumer's satisfaction with the efficacy of their product routine.

3. Exploring Research and Business Strategies for Sustainable Skincare

Suggest further research to understand the societal and environmental impacts of the skincare industry. Insights on consumer behavior can be connected to environmental impact in order to suggest strategies for a more sustainable future in the skincare industry.

Literature Review

RACE, CLASS AND ENVIRONMENTAL JUSTICE

To understand the impact of chemical waste from skincare products, it is important to consider the populations most affected by this waste. The term "environmental justice" integrates concepts of environmental racism and inequality and is defined as "the unequal distribution of environmental benefits and pollution burdens based on race." The origin of the term environmental justice comes from the United Nations' Rio declaration that a healthy environment is a basic right of all of Earth's inhabitants. However, in *Race, Class and Environmental Justice,*[50] Susan Clutters writes that environmental risks are unevenly distributed amongst different populations and societies.

After the EPA established an Environmental Equity Working group in 1990, their first tasks were to 1) evaluate the evidence that racial minority and low income groups bore a disproportionate burden of environmental risk and 2) to identify factors that contributed to different risk burdens and suggest strategies for improvement. In 1992, their signature report[51] was released that found a strong correlation between the location of commercial hazardous waste facilities and the percentage of minorities in those communities. Following the report, President Clinton

[50] Susan Clutter, *Race, Class and Environmental Justice* (Progress in Human Geography: 1995), 19,1,111-122.
[51] *Environmental Law Report No. 109* (American Bar Association: 1993), Adopted by the House of Delegates.

signed an Executive Order that required every federal agency to achieve the principle of environmental justice by addressing the human health and or environmental impacts of the agency's program and activities on minority or low income populations in the US.

In 2015, a study at the University of Michigan[52] looked at 30 years of demographic data and concluded that minority and low income communities are disproportionately targeted by industrities locating hazardous waste sites. The study aimed to answer which came first: was the hazardous waste site situated and a lower income community developed around it or were hazardous waste sites placed around lower income and minority communities? Researchers found the latter- a "consistent pattern over a 30-year period of placing hazardous waste facilities in neighborhoods where poor people and people of color live." Furthermore, hazardous waste sites were often built in neighborhoods going through transitions with upper income and predominately white families moving out and poor minority residents moving in, for a decade or two before the project arrived. Such changes resulted in a further eroding of resources and community ties in the neighborhood, creating a toxic environment for the people who stayed.

HEALTH+ ENVIRONMENTAL JUSTICE AS A SOCIAL ISSUE

Scientist Ami Zota applies environmental justice to the skincare industry in her paper "The Environmental Injustice of Beauty: Framing Chemical Exposure From Beauty Products as a Health Disparities Concern."[53] She writes that "an understanding of how both social and environmental factors jointly may influence health is necessary for the elimination of health disparities." As evidence of this need, the obstetrics and gynecology community issued a call to action to prevent toxic environmental chemical exposure on the human reproductive system.

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[52] Paul Mohai and Robin Saha, *Which came first, people or pollution? Assessing the disparate siting and post-siting demographic change hypotheses of environmental injustice* (IOP Science: Nov. 13, 2015).
[53] Ami Zota, "*The Environmental Injustice of Beauty.*"

Women of color, regardless of their socio-economic status, have higher levels of beauty product-related environmental chemicals in their body than white women. Even small exposure to these chemicals can lead to adverse reproductive health impacts, especially during critical periods of development in fertility and pregnancy.

Personal care products, most notably skincare products with chemically active ingredients, are a source of toxic chemical exposure for all women. Skincare products have limited and inconsistent disclosure of chemical ingredients and lack adequate data and testing to secure health and safety. While many ethnic and racial differences have been observed in the ingredients found in skincare products, Zota argues that social factors should be included to understand the social pressure and factors that influence the use of these unsafe products, as well as the cumulative impact on the environment. One example of the social pressure leading to unsafe product choices is the use of skin lightening creams. These products are among the most toxic, with the potential dangers of poisoning, neurotoxicity and kidney damage.

Multicultural markets are influenced by targeted advertisements that promote a mainstream, predominantly white standard of beauty and influence the use of unsafe products such as skin lightening creams. Marketing analysis and profiles on the global beauty industry show that multicultural markets are outpacing traditional beauty markets; African American consumers purchase 9x as many products than other groups and Latinos are the fastest growing beauty market.[54] Asian Americans spend 70% more on skincare products than any other group.[55]

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[54] *Looking Good: Appealing to Ethnic Consumers in the Beauty Aisle* (The Nielsen Company: 2013).
[55] Ibid.

Zota attributes the mass distribution of images that idealize whiteness and colorism, a social hierarchy built upon gradations of skin tone, to the use of dangerous skin-lightening products. In the United States, there are skincare products available to consumers that contain toxic chemicals such as hydroquinone, topical corticosteroids, or inorganic mercury. Multiple cases of mercury poisoning, characterized by damage to the kidneys and the central nervous system, have been reported after use of skin-lightening products.[56] Zota concludes that future clinical and public health research should consider beauty product usage as a factor that may shape health inequalities in women's reproductive health.

CONSUMER BEHAVIOR IN PURCHASING GREEN PRODUCTS

In the last five years, sustainable development has focused on environmental policies covering production and manufacturing. Only in recent years has a consumption perspective been highlighted, since high levels of consumption threaten the quality of the environment and sustainable development. In lieu of reducing consumption or reversing environmental damage, focus has shifted to promoting the purchase of environmentally sustainable products, or green products (GPs).

In a study of 80 papers written on consumer behavior in Lithuania and Austria between 2011-2017, environmental scientist Genovaite Liobikiene and pharmacist Jurga Bernatoniene classified the top factors that influence behavior to purchase sustainable products.[57] They found that consumers who viewed environmental problems to be of high importance were more likely to purchase GPs for the sake of the environment. Libobikiene and Bernatoniene also found a

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[56] Mitchell Berger, *Understanding Cosmetic Product Regulation Could Help Reduce Disparities* (American Journal of Obstetrics and Gynecology: February 2018), Volume 218, Issue 2, 264-265.
[57] Genovaite Liobikiene and Jurga Bernatoniene, *Why determinants of green purchase cannot be treated equally? The case of green cosmetics: Literature review* (Journal of Cleaner Science: Sept. 2017), 162:109-120.

significant gap between environmentally-conscious consumers' attitudes and their behavior. The gap is attributed to ingredient habits, affordability and accessibility of products, and unsatisfied expectations of GPs in the marketplace.

Papers analyzing green cosmetics declared that many similarities exist between organic food and organic cosmetics purchase behavior. Food products, as well as cosmetics, are seen as low-involvement products which entail minimal effort and consideration before a purchase decision. Health consciousness was highlighted as the most important factor influencing attitude towards organic cosmetics and as the main factor in the decision-making process. Overall, consumers believe that green products are better for their body, are safer than traditional cosmetics and promote a healthy lifestyle by containing ingredients which are beneficial for body and skin.

Connecting the role of society in determining consumption behavior, many of the research studies declared that social context (or sanctions) is one of the dominant factors influencing sustainable consumption. The paper called for future research to better understanding the role of environmentally-friendly social norms in determining green purchase behavior, which should be separated or attributed to hedonistic or normative goals.

ENVIRONMENTAL SAFETY OF PERSONAL CARE PRODUCTS

The paper "The Environmental Safety Aspects of Personal Care Products" [58] details how the environmental impact of personal care products is measured for the European market, but its framework could be applied to the US and global markets. Personal care products include a

[58] Johannes Tolls et al., *Environmental safety aspects of personal care products—A European perspective* (Journal of Environmental Toxicology: 2009).

number of ingredients with individual, substance-specific properties that influence product performance. When evaluating the safety of these products, both the individual chemical properties and the overall combination of ingredients should be considered. Standards for European personal care products are much stricter than in the US with over 30,000 banned ingredients, each requiring independent safety testing. The new European Regulation, Evaluation, Authorisation and Restriction of Chemicals (REACH) has a strong impact on the environmental safety assessment of cosmetic ingredients and will considerably increase attention to the environmental aspects of personal care products.

Two basic factors determine a product's environmental safety: 1) its environmental fate and 2) its potential effects on the environment. The "environmental fate" of a product is defined as the outcome of a chemical substance after it has been released into the natural environment. The outcome depends mainly on physicochemical properties, which include water solubility, absorption behavior, and volatility. The environmental fate also depends heavily on degradability, which is affected by microorganisms (biological degradation) present in sewage treatment plants, surface waters, and soils. These fate-relevant properties control the distribution of a chemical in the environmental compartments (water, soil, air) and its final removal by degradation processes. Environmental fate and information about the quantities emitted into the environment are used in exposure assessments to arrive at a Predicted Environmental Concentration (PEC).

The second assessment of environmental safety is the potential impact of a chemical on organisms living in the environmental compartments. This assessment depends on substance-specific properties, such as ecotoxicity. Data from standardized tests on representative organisms are required by European Chemicals Legislation. The result is a tiered

environmental effects assessment that calculates the Predicted No-Effect Concentration (PNEC), which is the maximum concentration of a chemical where no toxicological effects would be expected. The core of the environmental risk assessment is a comparison of the PEC and the PNEC. Only if the PEC is shown to not exceed the PNEC, can a substance or a product that contains it be considered ecologically safe.

DERMAL EXPOSURE + ABSORPTION

The World Health Organization's Environmental Health Criteria #242 and #235 state that the long-term effects of chemicals in contact with skin are measured by understanding dermal exposure and dermal absorption.[59,60] In many cases, toxins are more easily absorbed through the skin than through other organs, such as the lungs. Dermal exposure refers to the method and frequency in which a chemical comes in contact with the skin; dermal absorption is how a chemical moves from the outer surface of the skin into the skin and systemic circulation.

Dermal absorption is affected by many factors, including whether exposure is intended or unintentional, the physical state of the product, exposure duration and surface contact. The attributes of the skin itself are significant in measuring dermal absorption, and may vary with age, sex, and ethnic background. For this reason, is it complex and difficult to measure dermal absorption, so generalizations have been made about the duration of exposure, frequency of use, duration of dermal contact and the amount of substance used. Generally, skincare products are divided into leave-on products and rinse-off products, which have much shorter exposure. This information can be used for the risk assessment of individual ingredients if the content is know, but often it is not.

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[59] *Environmental Health Criteria 242: Dermal Exposure* (World Health Organization: 2015).
[60] *Environmental Health Criteria 235: Dermal Absorption* (World Health Organization: 2015).

Negative effects from the use of skincare products include irritation, sensitivity, and allergic reactions such as contact dermatitis, which continue to increase each year. As a result of changing product formulations and ingredients entering the market, new and unusual allergens are continuously emerging. Previous studies have shown that damaged skin, caused by UV damage, skin irritants, or compromised skin barrier, have a different dermal absorption than normal skin. Overall, more data is needed about the effects due to exposure of hazardous chemicals (e.g. allergens) in consumer products. A database of chemicals and their dermal absorption and toxicity should be created and shared across the industry to ensure the development of skincare products that are proven safe for consumer use.

The Societal and Environmental Impact of Individual Skincare Consumption

To connect skincare consumption to societal and environmental impact, it is crucial to understand the motivations and behaviors that drive consumption habits. Transformational change will result from determining the role social, demographic, and psychographic factors play in consumer's decision-making. The social environment affects the physical environment; the products a consumer chooses to use are eventually thrown out or washed into the aquatic ecosystem. To ensure all consumers have access to safe products, skincare formulations should be measured by their impact on individual and environmental health.

Data mining techniques are used to: 1) examine and group consumers based on their consumption behavior and 2) correlate predictors of skincare product consumption and waste. The resulting analysis can help explain how societal influences may impact an individual

consumer's exposure to environmental risk and their contribution to environmental damage through their skincare product choices. Using REACH standards of measuring environmental safety, consumer product waste can be examined through the end of its lifecycle, looking at both its environmental fate and its effect on aquatic organisms.

Understanding how American consumers choose, use, and discard skincare products offers a possibility to recognize key decision making and intervention points to enact change. Grouping consumers by behavior, rather than skin attributes, may suggestion trigger events or patterns that cause them to make unsafe choices. With the goal of creating a healthier society and environment for all, this information can lead to strategies and new business models that make safe skincare both accessible and identifiable.

A. The Predictors of Skincare Consumption Behavior

Data mining and machine learning techniques are used to understand the different groups of skincare consumers and their behaviors. There are two main questions asked in this analysis, each requiring a different form of data modeling:

1) What are the various groupings of skincare consumers?

   Analysis method: Clustering (using unsupervised machine learning)

2) What are the biggest predictors of how many products a person buys and doesn't use?

   Analysis method: Poisson Regression (using demographic and psychographic data)

I Preprocessing the Data

The sample data was obtained through an MIT COUHES-approved survey deployed to a random sample of 100 women in the United States.[61] Survey respondents were asked questions about their skincare knowledge, habits and routines. Because the survey was over 30 questions, only select data points were considered to answer the two research questions outlined above. The original data was cleaned and structured to prepare for analysis and machine learning applications.[62]

The purpose of the data analysis is to better understand the different groupings, or clusters, of skincare consumers based on their consumption habits and environmental factors. The secondary goal of the analysis is to understand the largest predictors on the amount skincare products that are purchased and not used. The variables examined for each consumer include: Age, Ethnicity, Climate, Skin Allergy, Skin Sensitivity, Ingredient Knowledge, Label Reading Habits, and Product Spend. The outcome measured is: Unused Products (calculated as the difference between the number of products owned and the number of products used).

II Correlation Visualization

A correlation visualization is used to see the relationship between variables identified as having a high impact on skin health: age, skin sensitivities, allergies, and ingredient knowledge.[63] Understanding the relationship between customer demographics and skincare consumption habits could be used to predict how their behavior may change. Changes in behavior may result from aging or after a trigger event, such as having an allergic reaction. In the visualization

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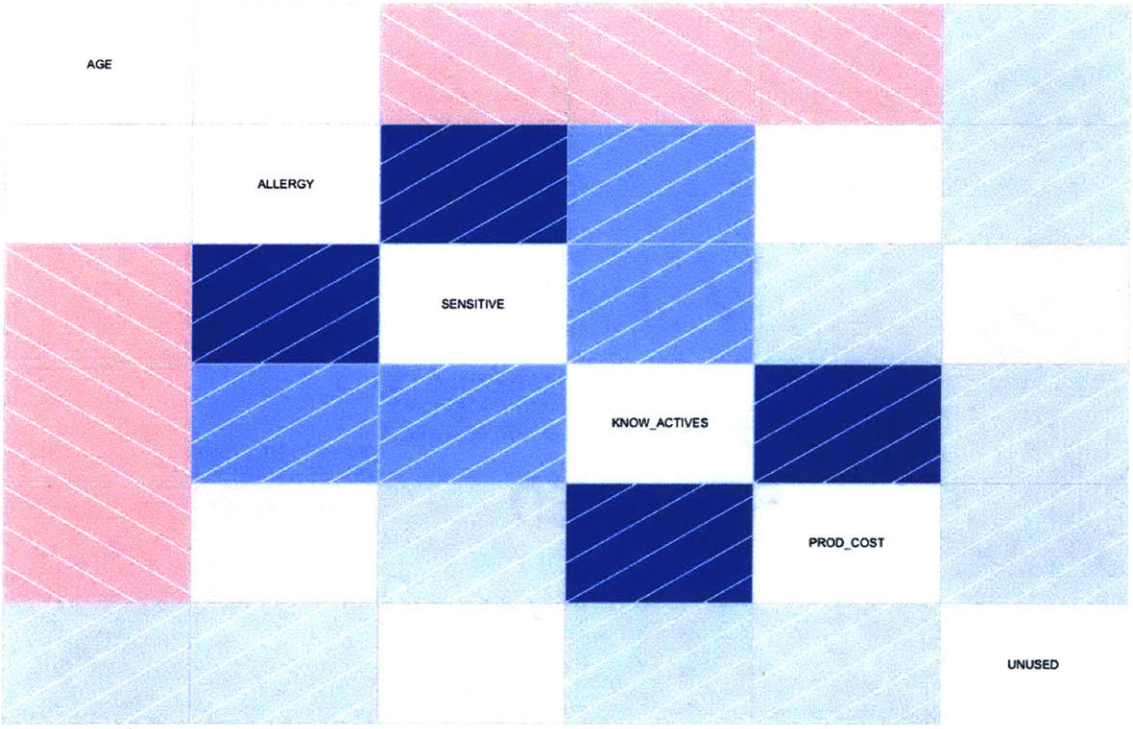
[61] See Appendix A.
[62] See Appendix B.
[63] Alexa Kimball, *Skin Differences, Needs, and Disorders Across Global Populations* (Journal of Investigative Dermatology Symposium Proceedings: Apr. 2008), Volume 13, Issue 1, 2-5.

below, blue identifies a positive correlation, while red identifies a negative correlation. Color intensity is proportional to the correlation coefficients.

Correlogram



Positive correlations: skin allergies + sensitive skin
ingredient knowledge + product cost
sensitive skin + ingredient knowledge
skin allergies + ingredient knowledge

Negative correlations: age + sensitive skin
age + ingredient knowledge
age + product cost

The correlogram shows a strong positive correlation between women having sensitive skin and reporting an allergic reaction to a skincare product. There is also a strong positive correlation between a woman's knowledge of ingredients and the amount of money she spends on products- a woman will spend more money on a skincare product when she is confident the

ingredients will work for her skin. The correlogram shows high negative correlation between age + sensitive skin, as well as age + ingredient knowledge and age + product cost.

The negative correlation between age and sensitive skin is surprising, but could be explained by the small data set of 100 women who are primarily between 25 and 40 years old. The relationship between age and sensitive skin should be examined with larger data set that has a wider age distribution. The European Academy of Dermatology has stated that the rate at which women are reporting skin sensitivities has increased to the point it is now a "global issue."[64] There are confounding variables that could explain the negative correlation between age and sensitive skin, such as: the effect of increased pollution and climate change on skin health, dietary differences for younger women, or an increased number of dermatologist visits, leading to higher number of Gen X and Millenial consumers diagnosed as having "sensitive skin." Additionally, these results could be explained by self-reported data being biased or younger women being more likely to respond to the survey than older women.

III Clustering

Currently the skincare industry groups consumers with the dissemination of 3 primary skin types: "oily," "combination," or "dry." As opposed to grouping by skin attributes, unsupervised machine learning was used to group skincare consumers into behavioral clusters based on environmental factors and transactional data. Unsupervised machine learning techniques allow the data to self-organize into groups and reveal underlying patterns. A Hierarchical Clustering algorithm (HCluster) was chosen due to the small data set and because this method reveals relationships, whereas non-hierarchical clustering does not.

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[64] S. Stander, *Sensitive Skin-A Global Challenge with Upcoming Solutions* (Journal of the European Academy of Dermatology and Venereology: Jan. 25, 2016), Volume 30, Issue S1.

Before running the HCluster, the 3 categorical variables were converted to factors (Ethnicity, Climate, and Read_Label). The 3 variables (Allergy, Sensitive, Know Actives) with a "1" or "0" became a factors with "Yes" or "No." The HCluster was used to plot a heatmap[65] and clustering was checked against the factors to ensure the clusters weren't grouped by any factor. The dendrogram, a type of tree diagram, showed 3 main clusters of skincare consumers, so the tree was cut into 3 groups. An examination of the groups show that the spit was relatively even between clusters.

The results reveal 3 primary clusters, where each cluster varies in median age, skin knowledge, product knowledge, and skin sensitivities. There is no significant grouping by ethnicity or by climate. To better understand the differences between clusters, the summary data for each cluster is referenced against the original data set, broken into cluster.[66] The medians of each dataset are compared and the means of the 3 factors with "Yes"/1 or "No"/O variables (Allergy, Sensitive, Know Actives) are computed.

COMPARING MEDIAN AND MEANS OF THE ORIGINAL DATA SET:

Group	Ethnicity	Age	Climate	Allergy (mean)	Sensitive (mean)	Know Actives (mean)	Read l-Label	Product Cost	Unused
1	n/a	36	n/a	1.5	1.64	1.08	3	$15	4
2	n/a	32	n/a	1.35	1.59	1.21	3	$13	5
3	n/a	46	n/a	1.37	1.56	1.11	4	$10	8
ALL	n/a	38	n/a	1.4	1.59	1.14	3	$12	6

[65] See Appendix C.
[66] See Appendix D.

Cluster 1:
High-Spending Women with Sensitive Skin Who Don't Know What Works

This group is women of median age (36 years old) who spend the most money on skincare ($15/per product); they rarely read product labels; they have the most allergic and most sensitive skin; however, they know the least about which active ingredients in skincare products work for them. Despite their lack of ingredient knowledge, the women in Cluster 1 have the least product waste, with a median of 4 unused products.

The amount of unused products for this group is surprising, but could be explained by the small data set or unmeasured behavior such as: they have sensitive skin so they exhibit more targeted purchasing (less willing to experiment, higher price point purchases) and therefore have less unused products. Or, because of their sensitive and allergic skin, they could be purchasing products from a dermatologist and not need to read labels or understand ingredients since the products are coming from a reliable source. Further exploration is needed to understand this behavior, some of which can be explained by the Poisson Regression log odds, which will indicate how significant the predictor sensitive skin is on unused products.

Cluster 2:
Young Women with Normal Skin and High Ingredient Knowledge

This group is the youngest women (median age: 32 years old) who spend the average amount on skincare ($13/per product); they read product labels the average amount; and they have the least allergic skin and median sensitive skin (although very similar to Cluster 3). They also have the most knowledge about what active ingredients work for them, and a median amount of 5 unused products.

There are several attributes of Cluster 2 that are unusual. First is that they are the youngest group, but have the least allergic skin. The correlogram shows age and skin allergies are negatively correlated, so it is unexpected to have a group of young consumers with the least amount of skin allergies. Their high ingredient knowledge could play a role in diminishing the number of negative or allergic reactions experienced from skincare products, since they know what ingredients to avoid. Another explanation is the small data set and limited number of data points. There could be a limitation with the model, considering age data starts at age 23, not 0 and is a continuous variable, whereas allergy is a factor with 2 levels. Either way, the correlation between skin allergies and age is inconclusive.

The other surprising relationship in this cluster is the highest knowledge of active ingredients and a median amount of unused products. Expected consumer behavior is that women who know what active ingredients to look for would choose the most efficacious products, and therefore have a low number of unused products since their products work for them. This behavior could be explained by confounding variables such as: their propensity to buy and try multiple products (serial "experimenters"); or a bias towards thinking they understand but not actually knowing their skin's attributes; or similarly, receiving the wrong information about what should work for their skin and therefore purchasing products that don't work and end up unused. The significance of ingredient knowledge on the amount of unused products can be explained in the poisson regression by looking at the log odds.

Cluster 3:

Older Women who Rarely Read Labels and Rarely Buy Products They Don't Use

This group is the oldest women (median age: 46) who spend the least amount of money ($10/per product); they read product labels the least; they have the least sensitive skin and median allergic skin (although very similar to Cluster 2) ; they have an average amount of knowledge about what active ingredients work for them, yet have the least amount of unused products.

Group 3 is most in-line with what is expected for the clustering; highest age and least sensitive skin is aligned with the high negative correlation between age and skin sensitivities. The amount of unused products could be explained generational differences in consumer behavior, because millennial consumers are more concerned about the safety of individual ingredients present in skincare formulations. A study by natural skincare brand Kari Gran found similar results- that likelihood of reading skincare product labels decreases with age.[67] The amount of unused products can be further explained by the Poisson Regression.

IV Poisson Regression

While there are many variables that may impact consumer's skincare product waste, it is important to understand the most significant predictors through a regression model. Regression models are used to understand which of the independent variables are related to the dependent variable (unused products). The regression model gives the log-odds of predictors, which is calculated by dividing the probability of having an unused product by the probability of having a

[67] Kari Gran, *Poll: Nearly 60% of American Women Read Beauty Product Labels, Check for Harmful Ingredients* (Cision PR Newswire: Aug. 5, 2015), https://www.prnewswire.com/news-releases/poll-nearly-60-of-american-women-read-beauty-product-labels-check-for-harmful-ingredients-300123881.html.

used product. Log-odds are common in data analysis because they are easily updated with new data.

A Poisson Regression is used because the measured outcome is a count that cannot be below "0", since it is the number of unused products that a person buys and does not use regularly. Because there are several instances of the count "0" (signifying there are no products a person buys and does not use regularly), it will prevent the skewed distribution from being transformed into a normal one. In choosing this model, it is understood that the Poisson model assumes the variance and the means are equal; which is checked in the analysis of the model (Appendix E). Dimension Reduction techniques are used to develop an efficient model to predict the amount of unused products a woman might have based on the environmental and physical data collected.[68]

POISSON REGRESSION MODEL COEFFICIENTS IN R:

```
Call:  glm(formula = UNUSED ~ ETHNICITY + AGE + CLIMATE + ALLERGY +
    SENSITIVE + KNOW_ACTIVES + READ_ILABEL + PROD_COST, family = poisson,
    data = skincare)

Coefficients:
            (Intercept)          ETHNICITYAsian          ETHNICITYBlack       ETHNICITYHispanic
               1.241000                0.125129               -0.093170                0.480936
ETHNICITYMiddle Eastern       ETHNICITYMultiple          ETHNICITYWhite                     AGE
               0.297627               -1.541464                0.028704                0.002823
              CLIMATEA                CLIMATEB                CLIMATEC                CLIMATED
               0.328311                0.588656                0.386614                0.233932
            ALLERGYYes           SENSITIVEYes         KNOW_ACTIVESYes       READ_ILABELHalf
              -0.184171                0.080687                0.615941                0.252053
      READ_ILABELMost         READ_ILABELNever    READ_ILABELSometimes               PROD_COST
              -0.211959                0.226031                0.038986               -0.001234

Degrees of Freedom: 66 Total (i.e. Null);  47 Residual
  (32 observations deleted due to missingness)
Null Deviance:      232.5
Residual Deviance: 181.2        AIC: 443.7
```

[68] See Appendix F.

The value of the coefficient relates to its significance on the measured outcome (unused products). The highest coefficient shows that for women who identify with multiple or mixed ethnicities, the log odds of having an unused product decreases by -1.54. Other predictors that are negatively related to the outcome include reading product labels "most of the time" and having a previous allergic reaction to skincare products. In other terms, if a consumer reads products labels "most of the time" or has had a previous allergic reaction to a skincare product, the log odds of buying a skincare product and not using it decrease.

For women who live in Climate B (Koppen-categorized "dry, desert and semi-arid" climates),[69] the log odds of having an unused product increases by 0.58. For women who know what active ingredients work for their skin, the log odds of having an unused product increases by 0.61. Product cost and age do not appear related to number of products a consumer buys and then doesn't use.

The log odds help answer questions that arise from the clustering of skincare consumers. The first question is around the log odds of sensitive skin on unused products, which does not seem very significant from the regression model. This means that women who have sensitive skin, a high number of unused products can be explained by other factors, including some behavior that was not included in this analysis.

The second question is around the log odds of active ingredient knowledge on unused products, which is negatively significant. When women know what active ingredients work for their skin, their log odds of having an unused product increases. This relationship needs further

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[69] *Koppen Climate Classification* (ISC Audubon), http://www.thesustainabilitycouncil.org/resources/the-koppen-climate-classification-system/.

exploration, including a comprehensive model that includes variables such as experimental purchasing, self-bias towards thinking they have ingredient knowledge, or receiving the wrong information.

In summary, the predictors that have the biggest impact on a consumer's number of unused products are: mixed-ethnicity, reading product labels, having a previous allergic skin reaction, living in dry climate, and understanding what active ingredients work for their skin.

V Results and Next Steps

There are several limitations of the data set that need to be considered when looking at the results. The first limitation is the size of the data set. 100 is a small number, so to draw any significant conclusions the same analysis would need to be done on a larger data set. This analysis provides a methodology for grouping various skincare consumers by their environmental and transactional data that can be repeated on new sets of data.

The next step for further investigation is to re-run the Clustering and Poisson Regression to see if similar results are found. After that, a Regression Tree based on the Clustering could be used to create a model that would identify consumers within the 3 clusters. Then a Poisson Regression using a larger data set could be compared to the results of the model created with the smaller data set of 100. If the models were similar and exhibited equal goodness of fit, the model could be used to estimate how many unused products a woman might have based on the predictors.

Another limitation of the data set is that the information is self-reported, which has been known to have a social desirability response bias- people answer the way they want to appear. Two techniques to reduce this bias are using a larger sample size and testing for reliability. The reliability of data comes from having consistent results with the same population over time. However, the best and most reliable data would be collected through ethnographic research rather than being self-reported.

A preferred method of data collection would be using user interviews and photographic documentation of products in people's bathroom cabinets. Product that are used and not used could be identified by the consumer, which would provide a more accurate number of "unused products" than calculating through indirect methods or relying on answers from memory. Additionally, attributes like "sensitive" skin or "allergic reaction" could be diagnosed by a dermatologist or by collecting dermal data from the individual, rather than being self-reported.

Another suggestion for future research is to explore the relationship between correlated variables such as knowledge of product ingredients and number unused products with further modeling. Of importance is including the measurement of identified confounding variables in this study- such as the source of their ingredient knowledge, the level of confidence in their knowledge and the more precise counts of unused products in the methods described above.

Overall, this analysis suggests there is a relationship between skincare product waste and an individual's knowledge about their skin and the ingredients that work for them. This is different than the current practice of segmenting skincare consumers by traditional demographic data

such as age, location, and ethnicity. Instead, consumers knowledge and behavior regarding skincare products should be considered in the pursuit of a zero-waste solution in the industry.

B. The Environmental Safety of Skincare Products

By design, skincare products like cleansers, masks and exfoliants are used in the shower or rinsed off with water. Even products intended to stay on the face, like moisturizers or serums, end up washed off at the end of the day. After their use, a significant amount of the product goes down the drain and enters the wastewater sewage system, ultimately ending up in the aquatic environment. Cosmetic ingredients are an emerging pollutant of aquatic life, continuously releasing large amounts of chemicals that have high ecological concern, such as UV filters, parabens, triclosan and microplastics.[70]

The European REACH framework is used to examine the environmental impact of US consumers' skincare routines. A random sample of 5 consumers was chosen and their routine is evaluated based on ingredients found in their cleanser and moisturizer. The REACH framework assesses a product's environmental safety by looking at: 1) the environmental fate, defined by its physicochemical properties and 2) the effects on organisms in the environment. The environmental fate determines the Predicted Environmental Concentration (PEC) and the effects on aquatic organisms informs a Predicted No-Effect Concentration (PNEC) for the substance. If the PEC is shown to not exceed the PNEC, a substance or a product that contains can be considered ecologically safe.

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[70] *Environmental safety aspects of personal care products.*

Because a specific score for PEC and PNEC has not yet been determined for the products in this analysis; the REACH framework is broadly applied to score safety. The resulting approach looks at existing research for ingredients found in the product to determine an assessment of environmental risk by environmental fate and effects on organisms. A environmental safety score is determined along the scale "no hazard," "mild hazard," "mild-to-moderate hazard," "moderate-to-severe hazard," or "severe hazard." The environmental safety score is compared to an individual safety score determined by the Environmental Working Group (EWG), a non-profit whose mission is to "to use the power of public information to protect public health and the environment." A safety score from the ThinkDirty app may also be presented; ThinkDirty is an independent product-comparison app that educates consumers on the potential toxic ingredients in their products. The safety scores are compared to the consumer's perception on the efficacy and safety of her skincare product routine.

It is important to consider the role that data transparency plays in the safety evaluation of skincare products. Per FDA label regulation,[71] skincare product ingredients are listed in descending order of their concentrations, but the exact amounts of their concentrations are not disclosed. Ingredients with less than 1% concentration can be listed in any order. Many aspects of chemical safety relate to the concentration of ingredients, so in this analysis, generalizations are made from the information listed on the product label.

Routine #1
Female; White; 48 years old; Librarian; Brea, CA

[71] *Cosmetic Labeling Guide (* US Food and Drug Administration).

She has no allergies and no skin sensitivities.

Her skincare routine is described as being "familiar and it works."

She is moderately satisfied with her skincare products.

Cleanser: Neutrogena Fresh Foaming Cleanser, $4.99

Ingredients in order of appearance:

Water, Glycerin, Lauryl Glucoside, Decyl Glucoside, Cocamidopropyl Betaine, Glycereth-7, Ammonium Laureth Sulfate, Sodium Cocoyl Sarcosinate, PEG-120 Methyl Glucose Dioleate, Glycol Stearate

Cocamide DEA- *surfactant (lathering); added to CA Proposition 65 List of Chemicals as known carcinogen in 2012; use restrictions, cancer, allergies/immunotoxicity, organ system toxicity (non-reproductive), contamination concerns*

Fragrance- *not regulated, allergies/immunotoxicity, irritation (skin, eyes, or lungs), organ system 'toxicity (non-reproductive), ecotoxicology*

DMDM Hydantoin- *preservative, formaldehyde releaser, allergies/immunotoxicity, irritation (skin, eyes, or lungs), use restrictions, cancer, contamination*

Tetrasodium EDTA, Citric Acid

Individual Safety Score:

7/10 ThinkDirty hazard score

dirty, high carcinogenicity

5/10 EWG hazard score

moderate overall hazard, moderate cancer concerns, moderate allergies, moderate use restrictions

Environmental Safety score: **Moderate-to-high-hazard**

Environmental Fate:

Cocamide DEA is fully degradable in a 28-day standard test for biodegradability and is thus described as readily biodegradable. QSAR calculations of the biodegradability of DMDM Hydantoin under aerobic conditions indicate that the substance can be expected to degrade quickly in the environment.[72] Fragrance compounds are airborne and in addition, most wastewater treatment methods do not remove fragrance compounds. Therefore, they are not easily broken down, as confirmed by a 1999 study by the EPA that concluded: "Fragrances

[72] *EPISUITE v. 3.12 (*USEPA: 2004).

(musks) are ubiquitous, persistent, bioaccumulative pollutants that are sometimes highly toxic; amino musk transformation products are toxicologically significant'.[73] Even materials that do not persist in the environment may act as they do because the supply is constantly being replenished."

Potential Effects on Environment Organisms:

The Danish Environmental Protection Agency[74] classifies Cocamide DEA as hazardous to the environment because of its acute toxicity to aquatic organisms and potential for bioaccumulation. Cocamide DEA can be described as toxic to moderately toxic to aquatic organisms with EC/LC50 values between 2-6 mg/l for Cocamide DEA. Cocamide DEA will is classified as hazardous to the environment with N; R51/53[75] (toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment) because of the acute toxicity of the substance and its potential for bioaccumulation. Based on the estimated partition coefficient (log Pow) value of -2.37, DMDM Hydantoin is not assessed to be bioaccumulative.[76] Provided that DMDM Hydantoin is degraded quickly in the environment, the substance is assessed not to be critical to the aquatic environment.

Because musk compounds tend to accumulate and break down slowly, they persist in the aquatic environment and accumulate in the fatty tissue of aquatic wildlife. Shellfish and fish have measurable levels of synthetic musk compounds in their tissues, a material considered to be a 'persistent organic pollutant'.[77]

Moisturizer- Neutrogena Oil-Free Moisture Sensitive Skin, $11.99

Ingredients in order of appearance:

Water, Glycerin, Ethylhexyl Palmitate, Dimethicone

Petrolatum- *potential carcinogen, EU limits chemical usage listing it as a carcinogen*

Cyclomethicone- *environmental toxicity concern*

Soybean (Glycine Soja) Sterols, Isopropyl Isostearate, Cetyl Alcohol, PEG-10 Soy Sterol, Glyceryl Stearate, PEG-100 Stearate, C12-15 Alkyl Benzoate, Carbomer, Tetrasodium EDTA, Sodium Hydroxide

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[73] Betty Bridges, *Fragrance: Emerging Health and Environmental Concerns* (Flavour and Fragrance Journal: 2002), 17:361-371.
[74] JR Larson, *Survey of Liquid Hand Soaps, Including Health and Environmental Assessments,* (Danish Ministry of the Environment: Environmental Protection Agency: 2006).
[75] Ibid.
[76] *EPISUITE v. 3.12* (USEPA: 2004)
[77] *Impacts of Atmospheric Pollution on Aquatic Ecosystems* (Issues in Ecology: 2004), Number 12.

Diazolidinyl Urea- *preservative, increases risk for contact dermatitis (American Academy of Dermatology) and releases formaldehyde, carcinogen, EU Commision limits the use of this chemical at 0.5% and indicates it is a formaldehyde releasing agent/carcinogen*

Ethylparaben

Methylparaben- *fragrance, preservative, mimics estrogen and may be hormone disruptor*

Propylparaben- *fragrance, preservative, limited by EU*

Individual Safety Score:

8/10 ThinkDirty hazard score

dirty, high allergy, high carcinogenicity

5/10 EWG hazard score

moderate overall hazard, moderate cancer concerns, high allergies, high use restrictions

Environmental Safety score: **High hazard**

Environmental Fate:

Cyclomethicone is a silicon-based cyclic compound that is non-biodegradable and has been shown to be persistent and bioaccumulative in humans and in wildlife.[78] It is also listed with concern as a "suspected environmental toxin" on Environment Canada's Domestic Substance List. Despite treatments that eliminate them relatively well from wastewater, parabens such as methylparaben and propylparaben are always present at low concentration levels in effluents of wastewater treatment plants. Although they are biodegradable, parabens are ubiquitous in surface water and sediments, due to consumption of paraben-based products and continuous introduction into the environment.[79]

Potential Effects on Environment Organisms:

Petrolatum is a byproduct of crude-oil production, including extraction through drilling, whose impacts on a global scale include: toxicity, climate change, and oil spills. Byproducts of crude oil include: Carbon dioxide (CO2); Carbon monoxide (CO); Sulfur dioxide (SO2); Nitrogen oxides (NOX) and Volatile Organic Compounds (VOC); Particulate matter (PM) as well as lead and

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[78] Michael Matthies et al, *The origin and evolution of assessment criteria for persistent, bioaccumulative and toxic (PBT) chemicals and persistent organic pollutants (POPs)* (Environmental Science: Processes and Inputs: 2016), Issue 9.

[79] C Haman et al, *Occurrence, Fate, and Behavior of Parabens in Aquatic Environments: A Review* (Water Res.:Jan 1, 2015) 1, 68, 1-11.

various air toxics when some types of petroleum are burned.[80] Carbon dioxide is a greenhouse gas and a source of global warming; SO2 causes acid rain, which is harmful to plants and to animals that live in water; NOX and VOCs contribute to ground-level ozone.[81] Parabens are known to cause long-term health impacts on marine mammals and high concentrations have been found in dolphins, sea otters and polar bears. Methylparaben is considered a hazardous substance according to OSHA 29 CFR 1910.1200. Trace concentrations of Methylparaben were found in the livers of polar bears from the Chukchi Sea and Beaufort Sea, which suggested widespread distribution of parabens in the oceanic environment.[82]

Routine #2
Female; Black; 42 years old; Healthcare worker; Buckeye, AZ

She has no allergies and has reported skin sensitivities.
Her skincare routine is not giving her desired results: "I just don't see the change yet that is supposed to happen regarding my routine facial wash."
She is slightly satisfied with her skincare products.

Cleanser: Mario Badescu Glycolic Foaming Cleanser, $16

Ingredients in order of appearance:

Sodium Lauryl Sulfate- *surfactant, mild irritant and possible allergic reaction, problem of contamination with 1,4-dioxane (FDA warning)*

Aqua (Water, Eau), Cocamidopropyl Betaine

Cocamide DEA- *added to CA Proposition 65 List of Chemicals as known carcinogen in 2012*

Glycolic Acid- *permitted at concentrations up to 10% and pH up to 3.5; known irritant and increase sun sensitivity- Health Canada Natural Health Products Database*

Salvia Officinalis (Sage) Leaf Extract, Hypericum Perforatum Extract, Chamomilla Recutita (Matricaria) Flower Extract, Althaea Officinalis Leaf/Root Extract, Achillea Millefolium Extract, Sodium Chloride

Fragrance- *not regulated, allergies/immunotoxicity, irritation (skin, eyes, or lungs), organ system toxicity (non-reproductive), ecotoxicology*

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[80] *Air Emission Sources* (US Environmental Protection Agency), https://www.epa.gov/air-emissions-inventories/air-emissions-sources.
[81] *Climate Change State of Knowledge* (US Environmental Protection Agency: 2016).
[82] Jingchuan Xue et al, *Elevated Accumulation of Parabens and their Metabolites in Marine Mammals from the United States Coastal Waters* (Environ. Sci. Technol.:2015), 49:20, 12071-12079.

Propylene Glycol

Methylparaben- *fragrance, preservative, mimics estrogen and may be hormone disruptor*

Propylparaben*- fragrance, preservative, limited by EU*

Individual Safety Score:

7/10 ThinkDirty hazard score

dirty, high carcinogenicity

Environmental Safety score: **Moderate-to-high hazard**

Environmental Fate:

1,4-dioxane, a potential byproduct of manufacturing sodium lauryl sulfate, is also persistent, otherwise meaning it does not easily degrade and can remain in the environment for long periods of time.[83] The FDA has not established or recommended a specific limit on the level of 1,4-dioxane in cosmetics. Sodium laureth sulfate is fully degradable in a 28-day standard test for ready biodegradability. Sodium laureth sulfate is also degradable under anaerobic conditions.[84]

Cocamide DEA is fully degradable in a 28-day standard test for biodegradability and is thus described as readily biodegradable.[85] Fragrance compounds are airborne and in addition, most wastewater treatment methods do not remove fragrance compounds. Therefore, they are not easily broken down.

Potential Effects on Environment Organisms:

Sodium Lauryl Sulfate is known to be highly toxic to some aquatic life, including phytoplankton, zooplankton and fish as well as Daphnia magna at low concentrations. Since Daphnia magna is an important food source for fish and other invertebrates, a decline in their populations may have implications for organisms at higher trophic levels. The acute effect of Sodium laureth sulfate to aquatic organisms can be described as toxic to moderately toxic with EC/LC50 values between 1.2-32 mg/l.[86]

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[83] Cara A.M. Bondi et al, *Human and Environmental Toxicity of Sodium Lauryl Sulfate (SLS): Evidence for Safe Use in Household Cleaning Products* (Sage Journals: Nov. 7, 2015).
[84] Ibid.
[85] *Survey of Liquid Hand Soaps,* Danish EPA.
[86] Stephanie R. Shipley, *The Effects of Sodium Lauryl Sulfate on the Abundance of Producers and Grazers in Aquatic Communities Using Freshwater Microcosms,* Thesis (Georgia Southern University: 2014).

The Danish Environmental Protection Agency classifies cocamide DEA as hazardous to the environment because of its acute toxicity to aquatic organisms and potential for bioaccumulation. Cocamide DEA can be described as toxic to moderately toxic to aquatic organisms with EC/LC50 values between 2-6 mg/l for Cocamide DEA.[87] Cocamide DEA is classified as hazardous to the environment because of the acute toxicity of the substance and its potential for bioaccumulation.

Because musk compounds tend to accumulate and break down slowly, they persist in the aquatic environment and accumulate in the fatty tissue of aquatic wildlife. Shellfish and fish have measurable levels of synthetic musk compounds in their tissues, a material considered to be a 'persistent organic pollutant'.[88]

Moisturizer- Acne.org AHA, $17.86

Ingredients in order of appearance:

Water

Glycolic Acid- *permitted at concentrations up to 10% and pH up to 3.5; known irritant and increase sun sensitivity- Health Canada*

Sodium Hydroxide- *restricted by EU*

C12-15 Alkyl Benzoate, Cetyl Palmitate, Sorbitan Stearate, Glycerin, Cyclomethicone, Glyceryl Stearate, Butylene Glycol, Licochalcone (Licorice Root Extract), Tocopheryl Acetate, Squalane

PEG-12 Glyceryl Distearate- *emulsifier; mild irritant, contamination concerns with 1, 4 dioxane, EU Cosing Cosmetic Ingredients and Substance List of Banned Ingredients*

PEG-100 Stearate, Magnesium Aluminum Silicate, Xanthan Gum, Sorbic Acid, 1,2-Hexanediol, Caprylyl Glycol.

Individual Safety Score:

n/a ThinkDirty hazard score

Other Acne.org products rated between 5-8

Environmental Safety score: **High Hazard**

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[87] *Survey of Liquid Hand Soaps,* Danish EPA.

[88] *Impacts of Atmospheric Pollution on Aquatic Ecosystems* (Issues in Ecology: 2004), Number 12.

Environmental Fate:

Current product labeling regulated by the FDA warns "this pesticide is toxic to wildlife" and that sewer treatment effluent containing sodium hydroxide may not be discharged into lakes, streams, ponds, estuaries, oceans, or public waters[89] - however, cosmetic products containing sodium hydroxide do end up in the water system. In addition, hazardous substance fact sheets list "Sodium Hydroxide in contact with water or moisture may generate enough heat to ignite combustibles." The Canadian Environmental Protection Agency's Environmental Emergency Regulations state "Sodium hydroxide was selected for risk evaluation because it is a substance that meets the criteria for corrosive substances that, if spilled, could be immediately harmful to humans and/or the environment."[90]

1,4-dioxane, a potential by-product of manufacturing PEG-12, is also persistent, otherwise meaning it does not easily degrade and can remain in the environment for long periods of time.[91] The FDA has not established or recommended a specific limit on the level of 1,4-dioxane in cosmetics.

Potential Effects on Environment Organisms:

Sodium hydroxide is listed by the EPA as a pesticide also known as "caustic soda" or a "corrosive substance." It is irritating to the skin, eyes and mucous membranes, and has been placed in Toxicity Category I (indicating the highest degree of toxicity) for acute eye and skin irritation effects by the FDA.[92] The CEPA states that $pH \leq 2$ or $pH \geq 11.5$ are considered corrosive to aquatic life and defines the impact as "a risk to endangered or threatened species or their habitat, or a significant life threatening risk to other wildlife; the incident causes significant disruption of public services or property damage and community health is or will be threatened; impacts of the incident on the environment are significant (e.g. fish killed)." [93]

Routine #3

Female; Asian; 34 years old; Data Analyst; San Diego, CA

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[89] *R.E.D Facts: Sodium Hydroxide* (US Environmental Protection Agency: 1992).
[90] *Substance Risk Evaluation: Sodium Hydroxide, Solution* (Environment Canada:2014).
[91] *Human and Environmental Toxicity of Sodium Lauryl Sulfate (SLS)* 2015.
[92] *R.E.D Facts: Sodium Hydroxide* (US Environmental Protection Agency: 1992).
[93] *Substance Risk Evaluation* (CEPA 2014).

She has no allergies and has reported skin sensitivities.

Her skincare routine is described as being effective: "It does what it claims." She is moderately satisfied with her skincare products.

Cleanser- Simple Micellar Cleansing Water, $5.99

Ingredients in order of appearance:

Water (Aqua), Hexylene Glycol, Glycerin, Chamomilla Recutita (Matricaria) Flower Extract, Panthenol, Niacinamide, Sodium Ascorbyl Phosphate

PEG-6 Caprylic/Capric Glycerides- *mild irritants, contamination concerns with ethylene oxide and 1,4-dioxane, EU Cosing Cosmetic Ingredients and Substance List of Banned Ingredients*

DMDM Hydantoin, Cetrimonium Chloride, Tetrasodium EDTA, Citric Acid, Potassium Chloride, Sodium Chloride

Iodopropynyl Butylcarbamate*- preservative, limited amounts in EU (0.001%), restricted for children's products, possible endocrine disrupter- American Journal of Contact Dermatitis, EU Cosing*

Individual Safety Score:

4/10 ThinkDirty hazard score

Half and half, mild carcinogenicity

2/10 EWG hazard score

Mild allergy concern

Environmental Safety score: **Mild-to-moderate Hazard**

Environmental Fate:

1,4-dioxane, a potential byproduct of manufacturing PEG-6, is persistent, otherwise meaning it does not easily degrade and can remain in the environment for long periods of time.[94] The FDA has not established or recommended a specific limit on the level of 1,4-dioxane in cosmetics. Based on stringent OECD test guidelines, Iodopropynyl Butylcarbamate (IPBC) is not considered readily biodegradable; however, it does biodegrade slowly in the environment. Its bioaccumulation potential (tendency to accumulate in the food chain) is low.[95]

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[94] *Human and Environmental Toxicity of Sodium Lauryl Sulfate (SLS)* 2015.

[95] *Product Safety Assessment: IPBC 100 Antimicrobia*l (Dow Chemical Company: 2015).

Potential Effects on Environment Organisms:

According to the EU Regulation (REACH), environmental precautions for using PEG- 6 include: "Do not discharge into drains/ surface waters/ groundwater." [96] Hazardous decomposition includes "oxidizes of carbon." Iodopropynyl Butylcarbamate has been known to be highly toxic to aquatic life. Listed on the Open Chemistry database website,[97] the aggregate GHS information provided by 1185 companies, included the danger hazard codes "H400 (96.02%): Very toxic to aquatic life [Warning Hazardous to the aquatic environment, acute hazard]" and "H410 (31.86%): Very toxic to aquatic life with long lasting effects [Warning Hazardous to the aquatic environment, long-term hazard]." IPBC is acutely toxic to fish, invertebrates, and algae; it has also been shown to be toxic to terrestrial organisms documented by acute studies in earthworms, terrestrial micro-organisms, and terrestrial plants. Due to the toxicity of IPBC to aquatic organisms, "the product should not be allowed to enter into sewers or be spilled on the ground or into any body of water."- EU DOW Product Safety Assessment.[98]

Moisturizer- Nature Republic Aloe Gel, $6.99

Ingredients in order of appearance:

Aloe vera leaf extract (92%), Ethanol, Glyceryl polyacrylate. Dipropylene glycol, Butylene Glycol, Glycerin, Propylene glycol, 1,2-hexanediol, Polyglutamic acid, Betaine, Sodium hyaluronate, Karen dulcis extract, Spearmint extract, Lemon balm extract, Carbomer,

Phage-60 hydrogenated castor oil*- mild irritant, contamination concerns with ethylene oxide and 1,4-dioxane, EU Cosing Cosmetic Ingredients and Substance List of Prohibited Substances*

Triethanolamine

Phenoxyethanol*- preservative, potential neurotoxin (FDA), can suppress central nervous system and cause vomiting and diarrhea, EU Cosing limit; US approved up to 1%*

Purified water, Disodium EDTA

Fragrance- *not regulated, allergies/immunotoxicity, irritation (skin, eyes, or lungs), organ system toxicity (non-reproductive), ecotoxicology*

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[96] *JEECHEM CTG-6 Safety Data Sheet* (Jeen International Corporation: 2017).

[97] *Iodopropynyl Butylcarbamate Compound Summary*, PubChem Open Chemistry database (National Center for Biotechnology Information), https://pubchem.ncbi.nlm.nih.gov/compound/62097.

[98] *Product Safety Assessment: IPBC 100 Antimicrobia*l (Dow Chemical Company: 2015).

Individual Safety Score:

7/10 ThinkDirty hazard score

high carcinogenicity

Environmental Safety score: **Mild-to-moderate Hazard**

Environmental Fate:

1,4-dioxane, a potential by-product of manufacturing phage-60, is persistent, otherwise meaning it does not easily degrade and can remain in the environment for long periods of time.[99] The FDA has not established or recommended a specific limit on the level of 1,4-dioxane in cosmetics.

Fragrance compounds are airborne and in addition, most wastewater treatment methods do not remove fragrance compounds. Therefore, they are not easily broken down.

Potential Effects on Environment Organisms:

According to a CIR review panel, Phenoxyethanol has been shown to be safe with levels up to 1% for humans,[100] however, less research has been done on the effects of Phenoxyethanol on aquatic species. The European Union Eco-label program data shows this substance has moderate acute toxicity to aquatic life, studied specifically in Household Cleaners.

Because musk compounds tend to accumulate and break down slowly, they persist in the aquatic environment and accumulate in the fatty tissue of aquatic wildlife. Shellfish and fish have measurable levels of synthetic musk compounds in their tissues, a material considered to be a 'persistent organic pollutant'.[101]

Routine #4
Female; Asian; 32 years old; Beautician; New York, NY

She has no allergies and no reported skin sensitivities.

Her skincare routine is described as being effective: "Pimple free and glowing skin"

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[99] *Human and Environmental Toxicity of Sodium Lauryl Sulfate (SLS)* 2015.

[100] *Cosmetic Ingredient Review Expert Panel: Final report on the safety assessment of Phenoxyethanol* (Journal of the American College of Toxicology), 9(2), 259-277.

[101] I*mpacts of Atmospheric Pollution on Aquatic Ecosystems* (Issues in Ecology: 2004), Number 12.

She is moderately satisfied with her skincare products.

Cleanser: Cerave Facial Cleanser, $10.99

Ingredients in order of appearance:

Purified Water, Cocamidopropyl Hydroxysultaine, Glycerin, Sodium Lauroyl Sarcosinate, PEG-150, Pentaerythrityl Tetrastearate

PEG-6 Caprylic/Capric Glycerides- *mild irritants, contamination concerns with ethylene oxide and 1,4-dioxane, EU Cosing Cosmetic Ingredients and Substance List of Banned Ingredients*

Niacinamide, Propylene Glycol, Sodium Methyl Cocoyl Taurate, Ceramide 3, Ceramide 6-II, Ceramide 1, Hyaluronic Acid, Cholesterol, Sodium Chloride, Phytosphingosine, Citric Acid, Edetate Disodium, Dihydrate, Sodium Lauroyl Lactylate

Methylparaben- *fragrance, preservative, mimics estrogen and may be a hormone disruptor*

Propylparaben*- fragrance, preservative, limited by EU*

Carbomer, Xanthan Gum

Individual Safety Score:

7/10 ThinkDirty hazard score

high carcinogenicity

4/10 EWG hazard score

Low overall hazard, low developmental toxicity, moderate allergies, moderate use restrictions

Environmental Safety score: **Mild-to-moderate Hazard**

Environmental Fate:

1,4-dioxane, a potential byproduct of manufacturing PEG-6 and PEG-150, is persistent, otherwise meaning it does not easily degrade and can remain in the environment for long periods of time.[102] The FDA has not established or recommended a specific limit on the level of 1,4-dioxane in cosmetics.

[102] *Human and Environmental Toxicity of Sodium Lauryl Sulfate (SLS)* 2015.

Despite treatments that eliminate them relatively well from wastewater, parabens such as methylparaben and propylparaben are always present at low concentration levels in effluents of wastewater treatment plants.[103] Although they are biodegradable, parabens are ubiquitous in surface water and sediments, due to consumption of paraben-based products and continuous introduction into the environment.

Potential Effects on Environment Organisms:

Parabens are known to cause long-term health impacts on marine mammals and high concentrations have been found in dolphins, sea otters and polar bears. Methylparaben is considered a hazardous substance according to OSHA 29 CFR 1910.1200. Trace concentrations of Methylparaben were found in the livers of polar bears from the Chukchi Sea and Beaufort Sea, which suggests widespread distribution of parabens in the oceanic environment.[104]

Xanthan gum has also been reported be fatally toxic to fish populations, as well as a registered pesticide. However, the EPA released an action memorandum in 2005, stating that a pesticide formulation of modified xanthan gum with a 0.1 to 0.3 glyoxal concentration would typical contain 2.9 to 7.5 ppm (parts per million) and at those low levels, would be considered to be low ecological effects or environmental fate concern.[105]

Moisturizer: Aveeno Clear Complexion Blemish Treatment Daily Moisturizer, $13.75

Ingredients in order of appearance:

Salicylic Acid (0.5%)- *considered drug/medication. skin irritations, Health Canada hotlist restricted for use in Cosmetic Products, allergy, EU Cosing limited use to 0.5% w/w when used as preservative*

Inactive Ingredients: Arachidyl Alcohol, Arachidyl Glucoside, Behenyl Alcohol, BHT, Bis Phenylpropyl Dimethicone, C12 15 Alkyl Benzoate

C13 14 Isoparaffin*- possible organ system toxicity, possible allergic reactions and possible carcinogen. Strict concentration of < 3% is recommended for cosmetics products (CIR)*

Cetearyl Alcohol, Cetearyl Glucoside, Dimethicone, Disodium EDTA, Ethylene Acrylic Acid Copolymer,

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[103] *The origin and evolution of assessment criteria for persistent, bioaccumulative and toxic (PBT) chemicals (*2015).
[104] *Elevated Accumulation of Parabens and their Metabolites in Marine Mammals* (2015).
[105] *Toxicity Studies for Xanthan gum on All Organism Groups* (PAN Pesticides Database - Chemical Toxicity Studies on Aquatic Organisms: 2016), http://www.pesticideinfo.org/List_AquireAll.jsp?Rec_Id=PC34724.

Fragrance- *not regulated, allergies/immunotoxicity, irritation (skin, eyes, or lungs), organ system toxicity (non-reproductive), ecotoxicology*

Glycerin, Glycine Soja Seed Extract (Soybean)

Isoceteth 20*- surfactant, contamination concerns with 1,4 dioxane*

Laureth 7*- surfactant, contamination concerns with 1,4-dioxane and ethylene oxide. Under Proposition 65, dioxane classified in California to cause cancer*

Methyl Gluceth 20, Polyacrylamide, PPG 10 Cetyl Ether, Water

Individual Safety Score:

7/10 ThinkDirty hazard score

high carcinogenicity

Environmental Safety score: **Mild-to-moderate Hazard**

Environmental Fate:

After 4 days, the biodegradation of salicylic acid, based on the DOC removal, was higher than 90%.[106] Under the test conditions, salicylic acid is therefore considered as readily biodegradable. A study done with the Australian Industrial Notifications and Assessment act found that the Isoceteth-10 PEC for rivers was 0.065 µg/L and for oceans was 0.006 µg/L.[107] Fragrance compounds are airborne and in addition, most wastewater treatment methods do not remove fragrance compounds. Therefore, they are not easily broken down.

1,4-dioxane, a potential byproduct of manufacturing Isoteth-10 and and Laureth-7, is persistent, otherwise meaning it does not easily degrade and can remain in the environment for long periods of time.[108] The FDA has not established or recommended a specific limit on the level of 1,4-dioxane in cosmetics.

Potential Effects on Environment Organisms:

The ecotoxicological effects of Salicylic Acid were studied in freshwater fish; the study found that there was significant oxidative stress reflected by an increased activity of selenium-dependent

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[106] *Salicylic acid: Biodegradation in Water (*European Chemicals Agency), https://echa.europa.eu/registration-dossier/-/registered-dossier/14544/5/3/2.
[107] *Isoceteth-20 Full Public Report* (Commonwealth of Australia: 2011).
[108] *Human and Environmental Toxicity of Sodium Lauryl Sulfate (SLS)* 2015.

glutathione peroxidase (GPx) and glutathione reductase (GRed) in the liver; additionally, it was possible to observe non-specific histological changes in gills.[109]

Isoceteth-20 Predicted No-Effect Concentration (PNEC) was shown to be >0.5 µg/L with an assessment factor of 100.[110] Comparing the PNEC to the PEC show that the risk quotients are <1 for both river and ocean compartments. This means that the chemical list is not expected to pose an unacceptable risk to the aquatic environment based on its use patterns.

C13 14 Isoparaffin is considered a pesticide inert by the Environmental Protection Agency, meaning that it could be considered to be toxic. C13-14 Isoparaffin is a mixture of hydrocarbons (mineral oils) derived from petroleum.[111] Petrolatum is a by product of crude-oil production, including extraction through drilling, whose impacts on a global scale include: toxicity, climate change, and oil spills. By products of crude oil include: Carbon dioxide (CO2); Carbon monoxide (CO); Sulfur dioxide (SO2); Nitrogen oxides (NOX) and Volatile Organic Compounds (VOC); Particulate matter (PM) as well as lead and various air toxics when some types of petroleum are burned. Carbon dioxide is a greenhouse gas and a source of global warming; SO2 causes acid rain, which is harmful to plants and to animals that live in water; NOX and VOCs contribute to ground-level ozone.[112]

Routine #5
Female; Hispanic/Multiple Ethnicities; 29 years old; Teacher; Fresno, CA

She has allergies and reported skin sensitivities.
Her skincare routine is described as being effective and environmentally conscious: "As natural and cruelty-free as I can get it, and treats my skin conditions"
She is extremely satisfied with her skincare products.

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[109] B Nunes et al., *Ecotoxicological effects of Salicylic Acid in the freshwater fish Salmo Trutta Fario: Antioxidant Mechanisms and Histological Alterations* (Environmental Science and Pollution Research: Aug. 7, 2014), Vol. 22, Issue 1, 667-678.

[110] *Isoceteth-20 Full Public Report* (Commonwealth of Australia: 2011).

[111] *C13-14 ISOPARAFFIN* (Cosmetic Glossary), http://xmedicimports.com/wp/index.php/2017/07/27/c13-14-isoparaffin/.

[112] *Air Emission Sources* (US Environmental Protection Agency), https://www.epa.gov/air-emissions-inventories/air-emissions-sources.

Cleanser: LUSH Herbalism Scrub, $17.50

Ingredients in order of appearance:

Prunus Amygdalus Dulcis (Sweet Almond) Seed Meal, Kaolin, Glycerine, Chlorophyllin-Copper Complex, Aqua, Urtica Dioica (Nettle) Extract, Vinegar, Rosmarinus Officinalis (Rosemary) Flower Extract, Oryza Sativa (Rice) Bran, Gardenia Florida Extract, Rosa Damascena Flower Extract, Anthemis Nobilis Flower Oil, Salvia Officinalis (Sage) Oil

Perfume- *possible carcinogen, possible allergic reaction*

Individual Safety Score:

7/10 ThinkDirty hazard score

high carcinogenicity

Environmental Safety score: **Mild Hazard**

Environmental Fate:

Fragrance compounds are airborne and in addition, most wastewater treatment methods do not remove fragrance compounds. Therefore, they are not easily broken down.

Potential effects on environment organisms:

Because musk compounds tend to accumulate and break down slowly, they persist in the aquatic environment and accumulate in the fatty tissue of aquatic wildlife. Shellfish and fish have measurable levels of synthetic musk compounds in their tissues, a material considered to be a 'persistent organic pollutant'.[113]

Moisturizer: Yes to Coconuts Eczema Spray, $9.95

Ingredients in order of appearance:

Water (Aqua), Cocamidopropyl Betaine, Sodium Coco-Sulfate, Lauramide DIPA, Glycerin, Cocos Nucifera (Coconut) Oil, Prunus Armeniaca (Apricot) Kernel Oil, Persea Gratissima (Avocado) Oi, Olea Europaea (Olive) Fruit Oil, Argania Spinosa Kernel Oil, Aleurites Moluccana Seed Extract, Hibiscus Sabdariffa Flower Extract, Morinda Citrifolia Fruit Extract, Musa Sapientum (Banana) Fruit Extract, Orchis Mascula Flower Extract, Psidium, Guajava Fruit Extract, Polyquaternium-10,

[113] *Impacts of Atmospheric Pollution on Aquatic Ecosystems* (Issues in Ecology: 2004), Number 12.

Citrus Grandis (Grapefruit) Seed Extract, Ascorbic Acid, Diisopropanolamine, Caprylyl Glycol, Sodium Hyaluronate

Phenoxyethanol- *preservative, potential neurotoxin (FDA), can suppress central nervous system and cause vomiting and diarrhea, EU Cosing limit*

Citric Acid, Sodium Benzoate, Potassium Sorbate

Fragrance- *not regulated, allergies/immunotoxicity, irritation (skin, eyes, or lungs), organ system toxicity (non-reproductive), ecotoxicology*

Individual Safety Score:

5/10 ThinkDirty hazard score

Half and half, mild carcinogenicity

Environmental Safety score: **Mild Hazard**

Environmental Fate:

Fragrance compounds are airborne and in addition, most wastewater treatment methods do not remove fragrance compounds. Therefore, they are not easily broken down.

Potential Effects on Environment Organisms:

According to a CIR review panel, Phenoxyethanol has been shown to be safe with levels up to 1% for humans,[114] however, less research has been done on the effects of Phenoxyethanol on aquatic species. European Union Eco-label program data shows this substance has moderate acute toxicity to aquatic life, studied specifically in Household Cleaners.

Because musk compounds tend to accumulate and break down slowly, they persist in the aquatic environment and accumulate in the fatty tissue of aquatic wildlife. Shellfish and fish have measurable levels of synthetic musk compounds in their tissues, a material considered to be a 'persistent organic pollutant'.[115]

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[114] *Cosmetic Ingredient Review Expert Panel: Final report on the safety assessment of Phenoxyethanol* (Journal of the American College of Toxicology), 9(2), 259-277

[115] *Impacts of Atmospheric Pollution on Aquatic Ecosystems* (Issues in Ecology: 2004), Number 12.

Discussion

The skincare products analyzed have an average of 22 ingredients. For consumers who read product labels, the volume of ingredient information is hard to decipher. It's unclear which are the ingredients that matter since the active ingredients are often not the highest concentrations in the product. If a consumer wants to understand the environmental safety of her product, she would have to cross reference each ingredient with a measured environmental impact, obtained from a variety of sources. A score for individual safety is easier to obtain by using the ThinkDirty and Environmental Working Group apps, however, the method of safety scoring for these apps often differs. There are discrepancies in the way ThinkDirty scores similar products. For the two products used by Consumer 5 , each has "fragrance" as the only identified problem ingredient, but the app gives one a hazard score of "7" and the other a "4".

Understanding the dosage of an ingredient is essential to understand its impact on individual and environmental health outcomes. The combinated dosages of ingredients in a product routine should be measured to know if a consumer is passing a safety threshold with their product routine. For example, Consumer 2 is using Glycolic Acid as an active ingredient in both her cleanser and her moisturizer. Glycolic Acid is permitted at concentrations up to 10%; however, since it is listed as ingredient #5 in the cleanser and ingredient #2 in the moisturizer, it's possible her overall exposure to the chemical surpasses the safety measure of 10%. Safety should be thought of holistically and as the sum of all parts: taking into account a customer's total skincare routine, skin attributes, and lifestyle.

There are several ingredients that are monitored by the FDA for food consumption, but not in cosmetics such as: pesticides C13 14 Isoparaffin and Sodium Hydroxide. A better understanding of dermal absorption for these chemicals is needed to understand if the effects are similar between skin contact and ingestion of these pesticides. It does not seem that Sodium Hydroxide, known as "caustic soda" should appear as a top ingredient in a leave-in skincare product. In skincare preparations, Sodium Hydroxide is used to establish and hold the pH of the product. Outside of the cosmetic industry, this ingredient is a known irritant to OSHA, who found it causes "irritation to eyes, skin, mucous membrane and causes skin burn and temporary loss of hair." They recommend consumers prevent any skin and eye contact with Sodium Hydroxide. Public safety information on ingredients is either lacking or presented with conflicting messages, leading to consumers being mislead and confused.

Byproducts of manufacturing, such as 1,4-dioxane were listed as a health and safety risk in many products studied in the analysis. The prevalence of 1,4-dioxane and other toxic byproducts proves why safety should be considered throughout the entire lifecycle of the product- from its creation to its end of life. The cosmetics sector should use good manufacturing practices (GMP) that account for safety and health impact throughout every step of product life cycle analysis. Additional consideration should be paid to product disposal and end of life: the analysis shows that some ingredients that are not proven to be toxic for humans are, in fact, toxic to aquatic life.

Conclusion

The skincare paradigm needs to shift from a high-consumption, high-turnover model to put individual and environmental safety at the forefront. The safest choice for the consumer is the result of targeted purchasing from knowing exactly what ingredients to look for, and which to avoid. The most sustainable thing to do for the environment as a society is to consume less. The skincare industry needs a consumer and corporate shift that reduces consumption through precision skincare and empowers consumers to make better and safer choices by knowing more about their skin.

Individual Safety

A database should be created that measures the efficacy of formulations on an ingredient and dosage level. This database could map individual skin attributes (including oil, moisture, pH, elasticity, tone) to the most effective ingredients based on the efficacy of products for people with similar attributes. Consumers are missing knowledge about their own skin and therefore find it hard with oversaturation of product offerings to differentiate and choose the products that will be safest and most efficacious for their needs. Certain ingredients may cause an allergic reaction in one person and not the next; safety should be considered on an individual basis that accounts for the changing and complex nature of skin health.

The efficacy database could be used to help promote buyer power and reduce bias in skincare product development. Knowing the effects of different ingredients on consumers and how it varies by race, ethnicity, location or other factors that affect skin health could overall improve

product-consumer fit. A product could have "clean" ingredients, but still be a mismatch for an individual consumer based on interactions with the other products in their routine or their skin's pH. Customized product recommendations should evolve to adapt with consumers needs at that given moment, making the consumer feedback on efficacy a core part of a new business model.

Knowledge about the most efficacious ingredients for different skin groups can be used to micro-market products to the people they will actually work best for, instead of marketing products to the general population. The information could also be used to develop customized formulations, down to the ingredient and dosage level. that solve a person's unique skin issues and understand how their skincare needs and products should change over time. While long-term health studies are common in the medical profession, no studies have been done tracking the longitudinal skin health of an individual over her lifetime, accounting for changes in environment, diet, products and other variables that might determine skin health outcomes.

Innovation in the industry should promote efficacy as well as empower consumers. By understanding their skin and what ingredients work for them, consumers take ownership of their skin health and can extend that knowledge to make informed product choices. Tracking safety on an individual level could also provide an immense amount of data for regulators who are trying to determine the toxicity and health impacts of different ingredients. A process that tracks the health outcome of ingredients and combinations of those ingredients will help lawmakers make decisions based on facts and measured outcome, rather than methods that use generalizations to calculate risk.

Environmental Safety

The skincare consumption analysis shows a relationship between ingredient knowledge and product consumption; the more someone knows about what will work for them, the more targeted purchases they make. More informed purchases reduces the trial-and-error cycle of buying skincare products only to find out they don't work and discard them. Information and empowerment are the keys to reducing consumption.

Skin sensitivity and previous allergic reactions to products are the largest predictors on if someone will buy a product and not use it. An ability to use consumer skin data to recommend formulations and predict outcomes will reduce the number of allergic reactions and negative health outcomes. Information about the performance of chemical ingredients in skincare will be able to highlight ingredient safety and efficacy, and create widespread change by identifying skincare products containing chemicals known to have negative health outcomes.

Aggregate data on consumers skincare product routines can, at scale, help measure the amounts of chemicals going into the waterstream. It can also alert consumers to the environmental impact of their products by drawing insights from collective data, which may include impact studies done in the EU or Australia, as in this research. More transparency is needed on the dosage amounts of ingredients in order to accurately measure individual health and environmental safety. A business model focused on custom skincare down to the ingredient dosage level has the capabilities to also precisely measure the environmental impact of each product.

Looking Towards the Future

The future of skincare retail will be centered around agency, efficacy and inclusivity. The new model will replace a traditional business model that weighs marketing over measured results and mass consumerism over sustainability and safety. Instead of creating products for general archetypes (with little focus on measuring efficacy), the industry will move towards product development with the individual in mind, focusing on their long-term health. In order for brands to be authentic about promoting skin health, they will need to measure and track impact. Consumers need a holistic view of skin health- not only by incorporating specific, dermal skin analysis but also accounting for the impact of other factors such as consumption behavior, genetics, and environment.

A new business model - creating skincare products specific for the individual, measuring their impact and adjusting the product to changes in the customer's skin health over time- will become the standard for the cosmetics industry. In a society where companies use personal data without the customer's knowledge, a new business model will change this paradigm, employing data transparency to include customers in product creation and give them the knowledge to make healthy choices, ultimately helping them feel more confident in their skin.

A sustainable future is one where consumption is minimized because every consumer is able to access the safest and most effective skincare product for them.

APPENDIX

A: Couhes Survey Questions

Demographic (optional)

Gender

- Male
- Female
- Prefer not to Answer

Occupation

- [short answer]

Ethnicity

- White
- Black
- Hispanic/Latino
- Asian/Pacific Islander
- Middle Eastern
- Native American
- Multiple ethnicities
- Prefer not to answer

Age

- [short answer]

Location

- [short answer]

Occupation

- [short answer]

Current Skincare Routine

What is your current skincare routine? List in order that you use- 1 being first, 2 being second

- Cleanser
- Toner
- Exfoliant/scrub
- Moisturizer
- Serum
- Facial oil
- Mask
- Sunscreen

On the scale of 0-10 how satisfied are you with your current skincare routine?

- 0: Extremely unsatisfied
- 2: Very Unsatisfied
- 4: Somewhat unsatisfied
- 5: Neutral
- 6: Somewhat satisfied
- 8: Very satisfied

10: Extremely satisfied

> *Why?* [short answer]

What are your top skincare concerns? Select all that apply.

Aging (preventative)
Aging (existing wrinkles)
Blackheads/congestion
Breakouts/acne
Discoloration/spots
Dryness
Dullness
Excess oil
Fine lines
Redness/Irritation
Sun damage
Other:

What are your skincare goals? How do you want your skin to change or what do you want it to look like?

[short answer]

Do you know what type of active ingredients in skincare products work for you?

Yes, it's _____
Maybe, I think _____
No
Other: _____

Do you look at ingredients of a product before you buy it?

Always -> [*what do you look for?]*
Often -> [*what do you look for?]*
Sometimes -> [*what do you look for?]*
Rarely
Never

What are the most important factors for you when purchasing a <u>new</u> skincare product?
Rank your top 3 in order of importance:

Product price
Product effectiveness (does it work for you?)
Clinical trials+results
User Testimonials/reviews
Product is green or organic
Product is vegan or cruelty free
Product does not contain preservatives/ fragrance
Latest technology
Packaging + presentation (brand)
Online community/social media
Personal recommendation (from friend)

Other

Current Skincare Routine (in-depth, included only in long survey)

What is the most important factor for you when purchasing skincare product multiple times?
**see above to compare buying first time with buying multiple times*

Product price
Product effectiveness (does it work for you?)
Clinical trials+results
User Testimonials/reviews
Product is green or organic
Product is vegan or cruelty free
Product does not contain preservatives/ fragrance
Latest technology
Packaging + presentation (brand)
Online community/social media
Personal recommendation (from friend)
Other

How much money do you spend per month on skincare products?

$0-10
$10-30
$30-50
$50-100
$100 or above
Other: _____

How many products do you purchase each month?

0
1
2
3
4
5
More than 5
Other:_____

How many products are currently in your cabinet? [short answer]

How many of those products do you use on a daily basis? [short answer]

How many are in the morning? _____
How many are in the evening?_____

How many products do you use on a weekly basis? [short answer]

Do you have sensitive skin?

Yes
No
Other: ____

What is your daily product routine?

Cleanser -> *(if selected) what brand and product?* _____
Toner -> *(if selected) what brand and product?* _____
Exfoliant/scrub -> *(if selected) what brand and product?* _____
Moisturizer -> *(if selected) what brand and product?* _____
Serum -> *(if selected) what brand and product?* _____
Facial oil -> *(if selected) what brand and product?* _____
Mask -> *(if selected) what brand and product?* _____
Sunscreen -> *(if selected) what brand and product?* _____

What is your favorite product? [short answer]

How did you discover it? [short answer]
How many months have you been using it? [short answer]
Why do you love it? [short answer]

What is your favorite skincare brand and why? [short answer]

Where do you normally purchase your beauty products? Rank your top 3 in order of

Department store (e.g. Nordstrom or Macy's)
Pharmacy (e.g. CVS or Walgreens)
Sephora, ULTA or similar
Boutique store (e.g. Kiehl's, Origins, Aesop)
Direct from skincare companies (e.g. Glossier or Skinceuticals)
Online marketplace (e.g. Beautycounter or Credo)
Health food store (e.g. Whole Foods)
Amazon
Instagram
Other: _____

Where do you normally discover new products?

Friends
Dermatologist
Esthetician/spa
Instagram
Blogs
Department store (e.g. Nordstrom or Macy's)
Pharmacy (e.g. CVS or Walgreens)
Sephora, ULTA or similar
Boutique store (e.g. Kiehl's, Origins, Aesop)
Digital brands (e.g. Glossier)
Other:_____

Are there any products you are looking for but haven't found yet? [short answer]

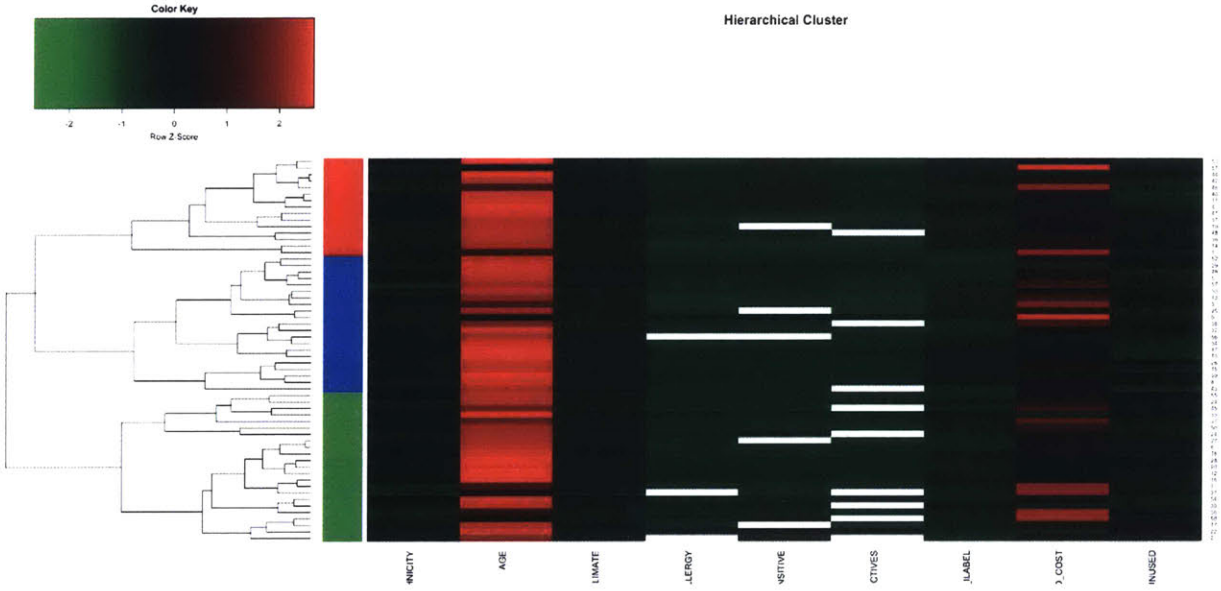
Does your routine change with the seasons? If so why? [short answer]

B: Data Pre-Processing for Machine Learning

Get rid of any male entries since we are focused on females
Get rid of entries with >4 empty fields
For the 99 people left, look at:

a. Age
b. Ethnicity
c. Location*
   *zip code transformed to Koppen climate type: A,B,C,D,E
d. Allergic reaction*
   *1=yes, 0=no, do not classify don't know
e. Sensitive skin*
   *1=yes, 0=no, do not classify don't know
f. Knowledge: ingredients*
   *1=yes, 0=no, do not classify maybe
g. Knowledge: read labels (always, most, half, sometimes, never)
h. Amount of money spent per product*
   * Money spent per product/ number products per month
i. Number of Unused Products*
   *Number of total products in cabinet-Number of weekly products used

C: Heatmap of Clusters Against Original Data



D: Clustering Data Summary

CLUSTER 1:

```
   ETHNICITY          AGE            CLIMATE         ALLERGY        SENSITIVE      KNOW_ACTIVES    READ_ILABEL     PROD_COST
Min.   :1.000   Min.   :27.00   Min.   :2.000   Min.   :1.0   Min.   :1.000   Min.   :1.000   Min.   :1   Min.   :  5.00
1st Qu.:6.500   1st Qu.:31.50   1st Qu.:5.000   1st Qu.:1.0   1st Qu.:1.000   1st Qu.:1.000   1st Qu.:2   1st Qu.: 10.00
Median :7.000   Median :36.00   Median :5.000   Median :1.5   Median :2.000   Median :1.000   Median :3   Median : 15.00
Mean   :5.867   Mean   :36.93   Mean   :5.267   Mean   :1.5   Mean   :1.643   Mean   :1.083   Mean   :3   Mean   : 27.67
3rd Qu.:7.000   3rd Qu.:40.50   3rd Qu.:6.000   3rd Qu.:2.0   3rd Qu.:2.000   3rd Qu.:1.000   3rd Qu.:4   3rd Qu.: 18.50
Max.   :7.000   Max.   :51.00   Max.   :6.000   Max.   :2.0   Max.   :2.000   Max.   :2.000   Max.   :5   Max.   :200.00
                                                NA's   :1     NA's   :1       NA's   :3
    UNUSED
Min.   : 1.000
1st Qu.: 3.000
Median : 4.000
Mean   : 4.933
3rd Qu.: 4.500
Max.   :13.000
```

	ETHNICITY	AGE	CLIMATE	ALLERGY	SENSITIVE	KNOW_ACTIVES	READ_ILABEL	PROD_COST	UNUSED
1	7	51	6	NA	2	NA	1	25	5
2	2	36	2	2	2	NA	5	200	10
3	7	45	5	2	2	1	3	10	4
4	7	32	6	1	1	1	4	10	4
5	7	42	5	1	1	1	4	45	3
6	7	30	5	1	2	1	4	10	3
7	7	35	6	2	NA	1	4	17	4
8	1	30	5	1	2	1	3	20	3
9	7	37	6	2	2	1	1	15	4
10	7	45	5	2	2	1	1	15	1
11	7	39	5	2	2	2	1	13	13
12	7	31	6	1	1	1	5	15	11
13	2	38	5	1	1	NA	3	5	4
14	7	27	6	2	1	1	3	5	4
15	6	36	6	1	2	1	3	10	1

CLUSTER 2:

```
   ETHNICITY          AGE            CLIMATE         ALLERGY        SENSITIVE      KNOW_ACTIVES    READ_ILABEL     PROD_COST
Min.   :2.000   Min.   :25.00   Min.   :2.000   Min.   :1.000   Min.   :1.000   Min.   :1.000   Min.   :1.000   Min.   :  0.0
1st Qu.:2.500   1st Qu.:28.50   1st Qu.:5.000   1st Qu.:1.000   1st Qu.:1.000   1st Qu.:1.000   1st Qu.:1.000   1st Qu.: 10.0
Median :7.000   Median :32.00   Median :5.000   Median :1.000   Median :2.000   Median :1.000   Median :3.000   Median : 13.0
Mean   :5.348   Mean   :34.74   Mean   :4.913   Mean   :1.348   Mean   :1.591   Mean   :1.211   Mean   :2.652   Mean   : 31.7
3rd Qu.:7.000   3rd Qu.:41.50   3rd Qu.:6.000   3rd Qu.:2.000   3rd Qu.:2.000   3rd Qu.:1.000   3rd Qu.:4.000   3rd Qu.: 28.0
Max.   :7.000   Max.   :50.00   Max.   :6.000   Max.   :2.000   Max.   :2.000   Max.   :2.000   Max.   :5.000   Max.   :250.0
                                                                NA's   :1       NA's   :4
    UNUSED
Min.   : 0.000
1st Qu.: 2.500
Median : 5.000
Mean   : 5.913
3rd Qu.: 9.000
Max.   :17.000
```

	ETHNICITY	AGE	CLIMATE	ALLERGY	SENSITIVE	KNOW_ACTIVES	READ_ILABEL	PROD_COST	UNUSED
1	2	28	2	2	2	2	1	0	10
2	2	27	2	1	1	NA	3	0	0
3	7	33	6	2	2	1	1	10	1
4	7	43	5	1	1	1	2	13	7
5	7	37	6	2	NA	1	3	13	8
6	2	32	2	1	2	NA	1	11	1
7	7	34	6	1	1	1	4	20	3
8	7	40	5	2	2	1	3	0	7
9	7	45	5	1	1	NA	2	36	9
10	3	46	5	1	1	1	4	18	6
11	7	32	4	2	2	1	2	12	10
12	7	28	5	1	2	NA	1	10	1
13	7	50	6	1	1	1	4	20	2
14	4	33	5	2	2	1	5	10	11
15	7	43	5	1	1	1	1	10	13
16	2	25	5	1	2	2	1	250	3
17	7	27	6	1	2	1	4	40	9
18	7	27	6	2	2	2	1	50	5
19	7	46	6	1	1	1	4	17	17
20	6	29	5	2	2	2	1	7	0
21	2	30	5	1	2	1	4	50	5
22	2	32	6	1	1	1	5	125	5
23	7	32	5	1	2	1	4	7	3

CLUSTER 3:

```
   ETHNICITY          AGE            CLIMATE         ALLERGY         SENSITIVE       KNOW_ACTIVES    READ_ILABEL     PROD_COST
Min.   :2.000   Min.   :23.00   Min.   :3.000   Min.   :1.000   Min.   :1.000   Min.   :1.000   Min.   :1.000   Min.   : 1.00
1st Qu.:3.000   1st Qu.:28.00   1st Qu.:5.000   1st Qu.:1.000   1st Qu.:1.000   1st Qu.:1.000   1st Qu.:2.000   1st Qu.: 7.00
Median :7.000   Median :46.00   Median :5.000   Median :1.000   Median :2.000   Median :1.000   Median :4.000   Median :10.00
Mean   :5.143   Mean   :41.86   Mean   :5.143   Mean   :1.368   Mean   :1.556   Mean   :1.105   Mean   :3.619   Mean   :17.67
3rd Qu.:7.000   3rd Qu.:52.00   3rd Qu.:6.000   3rd Qu.:2.000   3rd Qu.:2.000   3rd Qu.:1.000   3rd Qu.:5.000   3rd Qu.:15.00
Max.   :7.000   Max.   :63.00   Max.   :6.000   Max.   :2.000   Max.   :2.000   Max.   :2.000   Max.   :5.000   Max.   :83.00
                                                NA's   :2       NA's   :3       NA's   :2
     UNUSED
Min.   : 0.000
1st Qu.: 4.000
Median : 8.000
Mean   : 7.286
3rd Qu.:11.000
Max.   :14.000
```

	ETHNICITY	AGE	CLIMATE	ALLERGY	SENSITIVE	KNOW_ACTIVES	READ_ILABEL	PROD_COST	UNUSED
6 1	7	33	6	1	NA	1	4	5	8
2	2	24	5	2	2	1	4	50	14
3	2	26	6	NA	1	NA	5	83	12
4	2	27	6	1	1	1	4	40	5
5	7	56	6	2	2	1	5	10	4
6	4	53	4	1	1	1	2	10	11
7	6	26	5	1	1	2	1	10	4
8	2	52	4	1	1	1	5	10	13
9	7	42	6	2	2	1	5	5	9
10	7	52	4	1	1	1	4	10	0
11	7	53	6	1	2	1	5	10	2
12	7	49	6	NA	NA	1	4	5	4
13	7	50	4	1	1	NA	1	35	9
14	7	23	5	1	2	1	4	15	7
15	4	31	3	2	2	1	2	10	10
16	2	28	6	2	2	2	1	1	7
17	4	33	5	2	2	1	4	15	11
18	7	63	5	1	NA	1	2	15	9
19	7	46	6	2	2	1	5	5	2
20	3	51	5	1	2	1	5	20	1
21	7	61	5	1	1	1	4	7	11

E. Poisson Regression Testing

Cameron and Trivedi recommended using robust standard errors for the parameter estimates to control for mild violation of the distribution assumption that the variance equals the mean. I used the R package sandwich to obtain the standard errors and calculate the p-values.

Coefficient test with Sandwich method:

```
Call:
glm(formula = UNUSED ~ ETHNICITY + AGE + CLIMATE + ALLERGY +
    SENSITIVE + KNOW_ACTIVES + READ_ILABEL + PROD_COST, family = poisson,
    data = skincare)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-4.2887  -1.4073  -0.1699   0.9425   3.6517

Coefficients:
                          Estimate Std. Error z value Pr(>|z|)
(Intercept)              1.2409999  0.6019343   2.062  0.03924 *
ETHNICITYAsian           0.1251286  0.4326144   0.289  0.77240
ETHNICITYBlack          -0.0931698  0.4619393  -0.202  0.84016
ETHNICITYHispanic        0.4809360  0.4518170   1.064  0.28713
ETHNICITYMiddle Eastern  0.2976271  0.5587895   0.533  0.59429
ETHNICITYMultiple       -1.5414638  0.6076641  -2.537  0.01119 *
ETHNICITYWhite           0.0287040  0.4050243   0.071  0.94350
AGE                      0.0028229  0.0065426   0.431  0.66613
CLIMATEA                 0.3283107  0.3641152   0.902  0.36723
CLIMATEB                 0.5886556  0.2705296   2.176  0.02956 *
CLIMATEC                 0.3866142  0.2307630   1.675  0.09386 .
CLIMATED                 0.2339324  0.2524744   0.927  0.35416
ALLERGYYes              -0.1841712  0.1446535  -1.273  0.20295
SENSITIVEYes             0.0806869  0.1290212   0.625  0.53172
KNOW_ACTIVESYes          0.6159408  0.2271297   2.712  0.00669 **
READ_ILABELHalf          0.2520533  0.2384519   1.057  0.29049
READ_ILABELMost         -0.2119594  0.2494161  -0.850  0.39542
READ_ILABELNever         0.2260306  0.2129047   1.062  0.28839
READ_ILABELSometimes     0.0389862  0.2290186   0.170  0.86483
PROD_COST               -0.0012339  0.0009504  -1.298  0.19421
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

    Null deviance: 232.46  on 66  degrees of freedom
Residual deviance: 181.20  on 47  degrees of freedom
  (32 observations deleted due to missingness)
AIC: 443.71

Number of Fisher Scoring iterations: 5
```

The deviance residuals are almost normally distributed as they should be if the model is a good fit, median is only slightly below 0. I noticed that there are several variables which got dropped from the poisson regression including Ethnicity: American Indian and Reading the Ingredient Label:Always.

RP:
RP = (prevalence on exposed) / (prevalence on unexposed)

Ethnicity	
Asian	1.13%
Black	0.91%
Hispanic	1.62%
Middle Eastern	1.35%
Multiple	0.21%
White	1.03%
Age	1.00%
Climate	
A	1.39%
B	1.80%
C	1.47%
D	1.26%
Allergy_YES	0.83%
Sensitive_YES	1.08%
Know Actives_YES	1.85%
Read Label	
Half	1.28%
Most	0.81%
Never	1.25%
Sometimes	1.46%
Prod Cost	0.99%

Re-compute the Wald Tests using sandwich standard errors:

```
z test of coefficients:

                          Estimate Std. Error z value Pr(>|z|)
(Intercept)              1.2409999  0.7190936  1.7258  0.08439 .
ETHNICITYAsian           0.1251286  0.4646109  0.2693  0.78768
ETHNICITYBlack          -0.0931698  0.5391006 -0.1728  0.86279
ETHNICITYHispanic        0.4809360  0.4589021  1.0480  0.29463
ETHNICITYMiddle Eastern  0.2976271  0.4632989  0.6424  0.52061
ETHNICITYMultiple       -1.5414638  0.6421780 -2.4004  0.01638 *
ETHNICITYWhite           0.0287040  0.3829916  0.0749  0.94026
AGE                      0.0028229  0.0099351  0.2841  0.77631
CLIMATEA                 0.3283107  0.3801960  0.8635  0.38785
CLIMATEB                 0.5886556  0.4126505  1.4265  0.15372
CLIMATEC                 0.3866142  0.3574495  1.0816  0.27943
CLIMATED                 0.2339324  0.3691013  0.6338  0.52622
ALLERGYYes              -0.1841712  0.2325610 -0.7919  0.42840
SENSITIVEYes             0.0806869  0.2040609  0.3954  0.69254
KNOW_ACTIVESYes          0.6159408  0.3275862  1.8802  0.06008 .
READ_ILABELHalf          0.2520533  0.3785703  0.6658  0.50554
READ_ILABELMost         -0.2119594  0.3002248 -0.7060  0.48019
READ_ILABELNever         0.2260306  0.4040810  0.5594  0.57591
READ_ILABELSometimes     0.0389862  0.4003822  0.0974  0.92243
PROD_COST               -0.0012339  0.0016007 -0.7708  0.44082
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

After this test, the regressors still seem significant.

Testing the Model:

We can use the residual deviance to perform a goodness of fit test for the overall model because the residual deviance is the difference between the deviance of the current model and the maximum deviance of the ideal model where the predicted values are identical to the observed.

```
     res.deviance df            p
[1,]     181.1978 47 1.206023e-17
```

The goodness of fit chi test (p) is not significant, indicating that the model fits the data.