Unwearables: A Multilevel Perspective on the Abandonment of Wearable Electronic Devices in Healthcare Applications

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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I. Introduction

According to The Centers for Disease Control and Prevention (CDC), heart disease has been the leading cause of death in the United States for over seven decades, while other chronic illnesses such as chronic lower respiratory disease, kidney disease, and diabetes are all among the top ten killers in America (CDC, 2023; Heron & Anderson, 2016; Xu et al., 2021). With the growth of the internet of things and recent breakthroughs in machine learning, researchers have turned towards wearable electronic devices equipped with health sensing capabilities as a way to better diagnose, monitor, and manage these lethal diseases. In recent years, researchers have successfully demonstrated that ubiquitous smart devices like the Apple Watch can be used to provide actionable health data to patients and their healthcare providers (Pepplinkhuizen, 2022). Despite the enormous potential of wearables for health monitoring applications, these technologies have yet to live up to their transformational promise due to inconsistent use and high abandonment. In fact, Lee & Lee (2017) found that as many as 50% of users stopped wearing their smart devices weeks after purchase, while Hermsen et al. (2017) observed that over 80% of FitBit users abandoned their trackers after less than a year.

It's clear that wearables-based health monitoring systems have the potential to revolutionize healthcare by alerting patients and their medical teams of life-threatening diseases. However, in order to properly track a *chronic* illness, any monitoring device must be used consistently over the *long-term*. Although wearables have been shown to be technically capable of performing this task, the high abandonment rate of existing systems prevents them from doing so over the time frames needed to monitor chronic illnesses. The pattern of wearables falling into disuse suggests a gap in our understanding of the sociotechnical dynamics of wearables-assisted health monitoring systems. In this paper, I argue that a lack of stabilizing forces like cognitive

routines and behavioral norms undermine wearables as components of health monitoring systems, despite robust technical innovation and global trends that create an increasingly favorable environment for the widespread adoption of wearable technologies. I begin by reviewing the current state of wearable device capabilities and technology acceptance literature before proceeding to highlight the limitations of prior art. Next, I introduce Geels's (2007) multilevel perspective as a framework for understanding large technical systems and apply his methodology to healthcare-oriented wearable devices. I conclude by proposing future research directions inspired by the findings presented in this work.

II. Problem Definition: The Technology Acceptance Model Provides a Limited Understanding of Wearables as Sociotechnical System

In this section, I outline the technological trends that have enabled mobile health-sensing devices, examine the problem of abandonment in wearables, and introduce the Technology Acceptance Model. With this theoretical framework, I review existing literature on wearable abandonment before highlighting the gap in knowledge that this paper seeks to address.

A. Wearables Are Increasingly Capable of Health Monitoring

Wearable technology has been developed for centuries, beginning with the invention of eyeglasses in 1289 and continuing with devices like the abacus ring in 1644 (Ometov et al., 2021). In recent years, the rapid miniaturization of computerized circuits, improvements in compact yet highly accurate sensors, and increasing battery densities have paved the way for a new class of smart wearable devices like the Apple Watch, Oculus Rift Virtual Reality headset, and countless other products. In parallel, research into machine learning algorithms and applications has grown exponentially in the past decade as computing power and public interest has risen.

The confluence of these factors has inspired researchers to examine wearable devices as mobile health monitoring systems. These new systems leverage their proximity to users and improved mobile sensing capabilities to collect health data over extended periods of time. Scientists have shown that heart disease, COPD, kidney disease, and diabetes can all be monitored using sensors mounted on wearable smart devices (Huang et al., 2022; Rodriguez-León et al., 2021; Tiwari et al., 2021; Wieringa et al., 2017). Further, thanks to the ever-increasing computational powers of modern microchips, this data can be analyzed locally and privately using emerging artificial intelligence (AI) techniques. In fact, it's even possible to predict events such as rehospitalization with comparable accuracy to conventional clinical measurements due to the long-term nature of mobile monitoring and power of new AI models (Dunn et al., 2018).

Despite the extremely promising technical capabilities of these new systems, the potential of mobile health monitoring devices to actually improve patient outcomes is threatened by the high abandonment rates faced by existing wearable devices. Within weeks of owning a device, up to 50% of users have been shown to abandon their wearable (Lee & Lee, 2017). A year later, one study found that this figure jumps to 84%, while others find that abandonment rates range from 30% to 70% (Hermsen et al., 2017; Attig & Franke, 2023). Given the severity and pervasiveness of this phenomenon, several authors have examined the mechanisms behind wearable abandonment. Before reviewing these works, I introduce the Technology Acceptance Model as a framework with which to interpret their results.

B. Technology Acceptance Model Partially Explains Wearable Device Abandonment

One of the most widely used theories used to explain the adoption of technologies is the Technology Acceptance Model (TAM) introduced by Davis (1989). Shown in Figure 1, TAM

contends that there are two main factors that determine system use: perceived usefulness and perceived ease of use. In Davis's words, perceived usefulness is "the degree to which a person believes that using a particular system would enhance his or her job performance," whereas perceived ease of use "refers to the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989, pp 320).

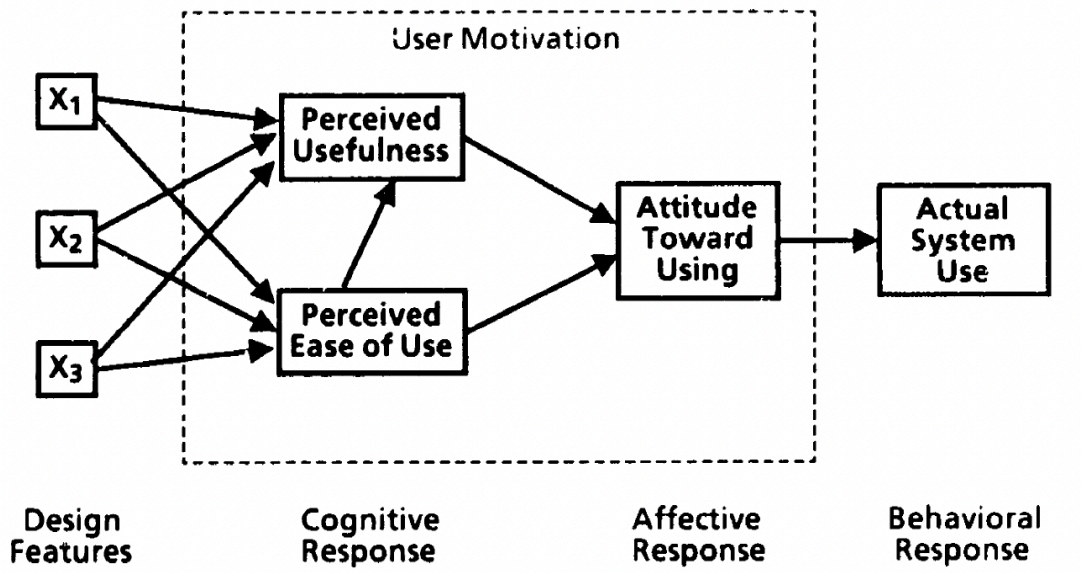

Figure 1. Davis's Technology Acceptance Model. In this model, the design features of a particular technology collectively inform the user's perceptions of usefulness and ease of use, which in turn define the user's attitude towards using a system and eventual use thereof (Davis et al., 1989, p. 24).

Although Davis initially proposed his framework in the context of workplace technologies (e.g., Excel for accounting), many studies have sought to apply TAM to healthcare-oriented systems. One review article looked at decades-worth of research that evaluated healthcare technology adoption using TAM and TAM-adjacent models (Holden & Karsh, 2010). These authors found that perceived usefulness was highly correlated with the adoption of healthcare technologies like "mobile healthcare systems" and "personal digital

assistants." These results suggest that TAM can appropriately be applied in workplaces other than conventional offices, such as healthcare facilities.

With this theoretical background, we are now ready to consider the existing literature on the abandonment of wearables. In many studies, usability concerns are one of the primary reasons cited for abandoning wearable devices. Specifically, surveys of users who have abandoned fitness trackers have found that former users tend to agree with statements along the lines of "I don't find it useful" (Fadhil, 2019). Furthermore, about 60% of former users responding to another survey indicated that they believed that the long term monitoring features were not useful (Maher et al., 2017). Still others found that the web applications and smartphone applications associated with these devices had low usability or required too much mental effort to use consistently (Coorevits & Coenen, 2016; Epstein et al., 2016). Over a third of participants in one study identified tracking discomfort, charging discomfort, device or app inconvenience, or lack of visual appeal as among their reasons for abandoning a wearable device (Attig & Franke, 2020). As a whole, the existing literature suggests that a perceived lack of usability or usefulness is among the main motivations for users abandoning their wearable devices, which is highly consistent with Davis's TAM.

C. Our Current Understanding is Limited to Device- and User-Level Factors

Clearly, there are ample studies that examine how the specific characteristics and features of wearable devices affect how they are perceived by their users. While device-scoped research reveals that one component of the wearables abandonment problem may be explained by TAM, this parochial device-level view must be complemented by a broader system-level perspective in order to gain a more holistic grasp of the abandonment problem. Indeed, to the author's knowledge, there is no review article that seeks to understand the abandonment of wearable

devices from a system-level view. Thus, this paper seeks to address the substantial gap in knowledge regarding how the systems put in place around healthcare-oriented wearable devices has helped or hindered the long-term use of these products and their retention of users. In particular, this paper synthesizes research into the micro, meso, and macro level factors that affect the use of wearable health monitoring systems using Geels's multilevel perspective, as outlined in the following research approach section.

III. Methods: Moving Beyond TAM with a Multilevel Perspective on Wearable Health Systems

The existing literature tends to focus on how disuse can arise from the specific technical attributes of wearables; however, there is a need for a synthesis of system-level, technical and nontechnical factors that may influence the abandonment problem. To support this analysis, I adopt the multilevel perspective (MLP) presented by Geels (2007) in his paper "Transformations of Large Technical Systems: A Multilevel Analysis of the Dutch Highway System (1950-2000)."

A. Basic Concepts of Geels's MLP

Prior to Geels's MLP, many scholars noted that there was a lack of research into the mechanisms that mediate changes in existing large technical systems (LTS). Although other frameworks can be used to analyze changes in LTS, they are limited in scope. Actor-network theory, for example, "neglects the influence of wider social structures" in favor of "local" actors and practices (Geels, 2007, p. 125). On the other hand, top-down approaches are limited by a focus on "macro-structures such as the economy or the government" (Geels, 2007, p. 125). The framework often used to evaluate wearable devices, TAM, falls into the former category, in which the scope of analysis is too narrow to completely capture the system-level complexity of the issue. To gain a new perspective on wearable abandonment while avoiding the trap of using

the same language and models (e.g., TAM) that have made little progress thus far, I adapt the framework presented by Geels.

Geels's MLP for evaluating changes in LTS consists of three distinct levels of analysis: the niche, regime, and landscape layers. The niche layer is where novel technologies emerge. Geels argues that niche-level actors cultivate social networks, provide a sandbox to trial new sociotechnical arrangements, and shape visions for new technologies. An example of this is seen in pilot programs and demonstration projects, which foster innovation "because they enable interactions between users, policy makers, firms, and engineers" (Geels, 2007, p. 129). For the purposes of this work, the niche-level factors consist of government subsidies for emerging wearable technologies, groups of entrepreneurs and similar outsider organizations, and wearable-oriented research communities.

At the regime layer, institutions, rules, and norms link individual actors to the macro layer and "account for the stability" of LTS (Geels, 2007, p. 128). In particular, momentum is conserved by established cognitive routines, behavioral norms, legal contracts, technical standards, and trade organizations. In this paper, I consider the cognitive routines of entities like health insurance companies and healthcare providers as well as the behavioral norms among caregivers and patients as regime-level factors.

Finally, the macro layer consists of global factors like environmental or cultural changes that are beyond the control of any individual actor or regime. In this paper, I consider two major factors as landscape level events: 1) an increased cultural emphasis on global public health issues and 2) demographic changes that lead to an increase in the number of people with chronic illness.

With this understanding of the three layers of the MLP, we can now see how this framework explains system transformations. Geels proposes that changes in LTS systems occur as follows: actors in a niche may propose that a new product solves existing problems in a regime. However, due to the stability in a regime, this new product may not be accepted unless a landscape change takes place. At this juncture, a sufficiently developed niche innovation may break through and become the norm. To provide further clarity, this process is visualized in Figure 2.

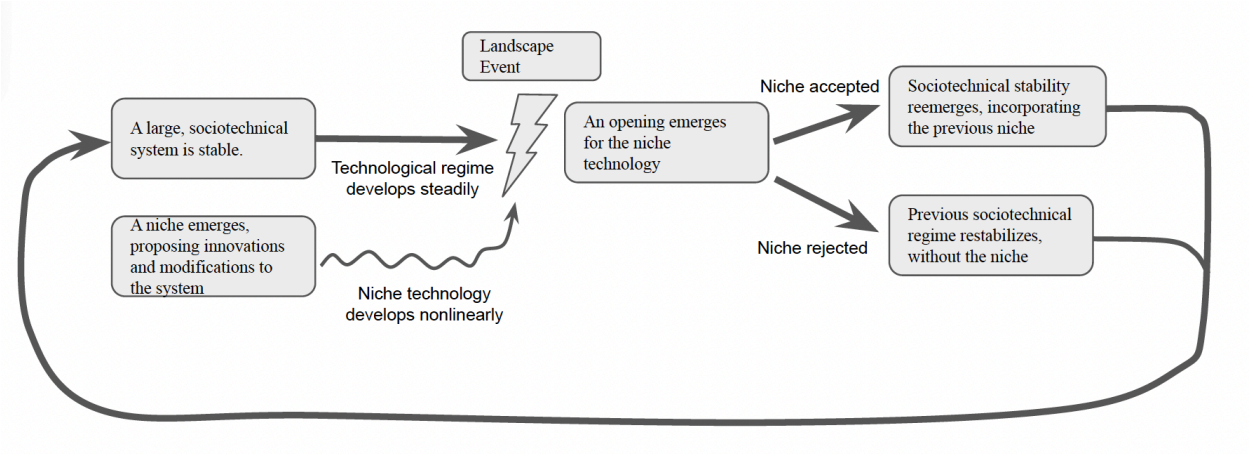

Figure 2. Geels' Multilevel Perspective. The left hand side represents the current state of the system, in which there is a stable arrangement that involves devices like the Apple Watch and FitBit. Landscape level events like increased awareness of chronic diseases, rising healthcare costs, and an aging population could create an opening for this new technology to become part of the sociotechnical regime, as depicted by the lightning bolt. At this point, stability will eventually reemerge through one of two paths: either the niche technology will be integrated into the sociotechnical regime, or it will be rejected. In either case, the cycle continues with a stable regime reemerging and new niches potentially progressing in parallel.

B. MLP Can Be Readily Applied to Wearable Devices

To evaluate the abandonment of wearable devices using the MLP, I propose the following approach which is also shown in Figure 3. First, I gather evidence by reviewing the literature. In particular, I attempt to achieve a multimodal analysis by looking at review articles regarding

wearable technology retention rates, papers with direct quotes of user views and opinions, and research into more macro-level factors like economic incentives and global trends. As evidence is collected, I filter the factors presented in the literature into micro, meso, and macro categories. With these broad labels, I then identify how these factors map onto the framework illustrated in Figure 2. Finally, I conclude by comparing the mapping to Geels's theory and highlight how factors at the various levels of analysis may contribute to the wearables abandonment problem.

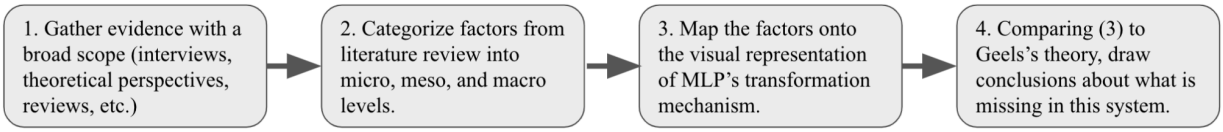

Figure 3. The four steps of this paper's research approach. 1) Gather evidence from a variety of sources. 2) Categorize into micro, meso, and macro levels 3) Map the factors from (2) onto the MLP from Figure 2. 4) Compare with Geels and draw conclusions

IV. Results: Abundant Technological Innovation Must Be Complemented by Proportional Social Innovation

Evaluating wearable devices through the lens of Geels's MLP, it becomes evident that social innovation is needed to promote the long-term use and retention of wearable devices for healthcare applications. Table I classifies various actors within the sociotechnical system of healthcare wearables into the niche, regime, and landscape levels of analysis. Factors highlighted in green currently add stability to the existing sociotechnical paradigm of wearables for healthcare applications, while those highlighted in red represent an unfulfilled need or factor that may undermine wearables as a sociotechnical system. In the remainder of this section, I argue:

1. There is a lively technological niche that nurtures emerging wearables for healthcare.
2. Landscape-level global health trends may provide a window of opportunity for new systems.

3. The current network of regime-level actors is insufficient to stabilize and give momentum to this transformation, highlighting a need for regime-level social innovation and change.

Table I. Wearables Factors Filtered into the MLP Levels of Analysis

Level	Characteristic from Geels	Example in Wearables
Niche	Government Subsidies	CHIPS and Science Act, et al.
	Construction of a Sociotechnical Configuration	Awareness of, but no action to fill, the "missing dimension"
	Developing Novelty Technologies	Emerging form factors (e.g. smart garments and implants)
		Research on AI in healthcare
Regime	Behavioral Norms	Digital fitness competitions
	Sense of Identity	Perceived lack of personalization
	Cognitive Routines	Healthcare providers are entrenched in old ways
		User unwillingness to learn and maintain new devices
Landscape	Cultural Changes	More global attention on public health
	Demographic Changes	Growing populations with chronic illness

A. Sustained Technological Evolution Improves Wearables as Health Monitoring Tools

In its current form, the wearables niche ardently fulfills its duty to "carry, nurture, and develop novelties" (Geels, 2007, pp. 130). As defined by Geels, the niche is a furnace in which the technologies of tomorrow coalesce through the impulses of entrepreneurs, researchers, and policymakers. Continuing this metaphor, the furnace for health-oriented wearables is scalding

hot, fueled by government subsidies for computer chips, endlessly growing interest in AI research, and a lively ecosystem of engineers, scientists, and entrepreneurs forging the next generation of wearable devices.

Over the past two years, governments around the world have been pouring public funds into R&D projects for semiconductor chips. Given that chips are the backbone of all contemporary wearable devices, to develop and improve microchips is to develop and improve wearables. In 2022, the United States government provisioned $52.7 billion to promote semiconductors research, development, manufacturing, and education initiatives through the CHIPS and Science Act (*The White House*, 2022). Moving abroad, Japan unveiled a subsidy for its chip firm Rapidus to the tune of $3.89 billion in April 2024 (Chiang, 2024). In May of the same year, South Korea splashed $19 billion on its own chip-making firms, "citing a need to keep up" with global competitors (Yang, 2024). Two days later, China announced a $47.5 billion fund aimed at bolstering its domestic chip manufacturing capabilities (Bao, 2024). With these investments, governments around the world nurture a "technological niche, in which public subsidies enable networks of actors to work on new technologies" that directly benefit wearables (Geels, 2007, pp. 128).

Entrepreneurs and researchers are also poised to disrupt the existing generation of health-oriented wearable devices by developing new form factors and empowering products with AI capabilities. In a public-private partnership, Providence, RI-based Nautilus Defense is collaborating with the University of Virginia and University of Michigan to design textile-based wearable systems with financial support from the Office of the Director of National Intelligence for its "SMARTe PANTS" project (Nautilus Defense, 2024). Others such as Elon Musk's Neuralink seek to restore the agency and digital autonomy of persons with quadriplegia through

neural implants, which, colloquially, read users' minds in order to control other digital devices without motion (Neuralink, 2024). In both cases, the uncommon, protectionist funding that comes from government subsidies or a billionaire's passion project enables radical novelties to be "developed by actors who deviate from regime rules," like the need to have immediate economic viability (Geels, 2007, pp. 133).

Although novel products like bleeding-edge microchips, smart textiles, and brain implants "cannot survive on mainstream markets," these "hopeful monstrosities" currently receive the protection of a lively niche through mechanisms like public subsidies, strong outsider groups such as Musk's Neuralink, and pilot projects such as the SMARTe PANTS program (Geels, 2007, pp. 129). In the near future, sufficiently developed and stabilized niche innovations may have an opening to transform the current system of wearables, taking advantage of an opportunity presented by landscape level events.

B. Global Health Factors Provide an Opening for New Wearables

As conceptualized by Geels, landscape level events can place pressure on the existing sociotechnical configuration, allowing technologies from the niche to break through and emerge as a stable replacement for the previous system (Geels, 2007, pp. 130). In this vein, there are two major events that are poised to disrupt the sociotechnical status quo and provide an opening for alternative healthcare monitoring systems: 1) increasing attention to global public health challenges and 2) growing populations with chronic illness.

Since 2020, searches for "global public health" have trended upwards, as shown in the Google Trends analysis in Figure 4. Somewhat surprisingly, this trend appears not to have coincided perfectly with the most notable global public health crisis of the 2000s, COVID-19. Nevertheless, with public health increasingly on the minds of the public, there may be an

increase in interest and desire for technologies that can help manage future crises, providing an opportunity for wearable devices to gain popularity.

Figure 4. Google Trends analysis for "global public health." (Google Trends, 2024).

The rising interest in global public health comes as no surprise given recent reports from the World Health Organization (WHO). According to the director of the WHO, chronic illnesses "take an immense and increasing toll on lives" (United Nations, 2023). By 2050, the report anticipates that the number of deaths attributed to chronic illness will increase by 90%, accounting for 86% of all fatalities (United Nations, 2023). These morbid statistics and the concomitant global focus on public health represent the lightning bolt from Figure 2, sending a shock to the existing healthcare monitoring system and creating an increasingly urgent need for widespread illness prevention and management tools. If the number of patients with chronic illness increases dramatically without a proportional increase in the number of healthcare providers, new chronic illness monitoring tools like wearable devices will be needed to help manage the influx of infirm individuals. For wearables to truly empower patients and providers with actionable chronic illness data, however, regime-level changes are needed to foster stability and support sustained, long-term use.

C. Regime-Level, Stabilizing Forces Are Needed to Promote Long-Term Use

According to Geels, "system transformation is enacted at the regime level of the MLP" (2007, pp. 133). In particular, stability emerges through mechanisms including cognitive

routines, behavioral norms, and perceptions of identity. Thus, despite a lively technological niche and several landscape level factors that might improve the likelihood of long-term wearables adoption, there must be strong regime-level stabilizing factors to realize a true transformation.

Regime-level shifts in rules, attitudes, goals, and the policies enacted to achieve them may be needed to bolster the long term use of wearables. As an example, economic incentive programs may be able to increase patients' desire to adopt and continually use wearables for illness tracking purposes. Although Soliño-Fernandez et al. (2019) found that incentives like "providing healthcare credits, insurance premium discounts, and wellness products discounts" increased users' willingness to adopt and use wearables, such programs have not gained mass adoption by insurance providers. In 2018, only six million Americans were eligible for such programs, despite research that suggests such incentives may increase user activity and wearable retention (O'Neill, 2018). One possible explanation for this is that existing cognitive routines among insurers often prioritize traditional risk assessments and cost-control measures that do not emphasize preventive, tech-driven healthcare solutions like wearables. A regime-level shift might entail insurers adopting a progressive mindset that embraces wearables as proactive tools for health monitoring, integrating them as a central part of risk management and patient engagement strategies. Indeed, this phenomenon is indicative of a need for a changing of the cognitive routines currently entrenched in regime-level actors like the insurance industry.

Likewise, other deep-rooted cognitive routines for both consumers and healthcare providers may need to evolve in order to improve the stability and momentum of future wearable healthcare systems. One study found that technological anxiety posed a significant barrier to using new devices to manage COPD (Niño de Gúsman Quispe et al., 2021). Threats to wearable retention like this likely need a multilevel approach to resolution. From the niche level, device

and system characteristics will need to be developed in such a way that minimizes user anxiety, perhaps by analogizing the new technology to existing devices that users might be more familiar with. Of equal importance, action should be taken to help shift the cognitive routines of users to ease their anxiety and help them feel more comfortable with new health management tools. In this vein, a future research direction might look at how healthcare providers and other caregivers might reduce technological anxiety among patients using wearable devices as illness management tools.

Although there is great demand for meso-layer innovations to improve wearable retention rates, there are some regime-level factors that already support long-term wearable use. One behavioral norm that has been shown to increase the retention of wearables is the use of digital competitions for step counts and other fitness goals. Canhoto and Arp (2017) argue that "gamifying the wearable experience can help with improving long-term use." However, current implementations of this type of system are typically limited to fitness-related goals; a future research direction could clarify whether there is scope for gamification of illness-oriented wearables, which would introduce new concerns such as a demand for greater privacy. Adding an element sort of gamification might convert the use of wearable devices for health from a burden to a source of pride or joy. Regardless, it is clear that regime-level innovations can create or alter behavioral patterns to be more conducive to long-term wearables use.

V. Conclusion

We have seen that despite their technical capability to monitor chronic illnesses, wearable devices often fail in practice due to widespread abandonment. Although previous works have used Davis's TAM to investigate the mechanisms behind this dynamic, these studies often focus on the technological and device-level factors that contribute to the rejection of wearables and

lack a broader, systems and sociotechnical perspective. By using Geels's MLP, we saw how factors at the niche, regime, and landscape level mediate the retention of wearables. Ever-increasing populations of individuals with chronic illness and an increasing focus on global public health may create an opening through which niche technologies can begin to dominate. With ample government subsidies, outsider-entrepreneurs, and a lively research community, the wearables niche is poised to contribute new technologies that may overcome some of the technical weaknesses of their predecessors. However, without social innovation to create and maintain regime-level stabilizing forces, these technologies will likely follow similar trajectories to contemporary wearables and face high abandonment.

While solving this issue is beyond the scope of this paper, this work has highlighted some future research directions to develop an even deeper understanding of the problem. There is plenty of evidence that economic incentives can increase willingness to use wearables, but there is no systematic research into why people hesitate to participate in such programs. A regime-level behavioral norm that could also increase wearable retention rates is gamification. While this has been shown to increase retention when applied to fitness related data, there would be serious privacy concerns and ethical questions that would need to be researched before translating this method to illness-oriented data. Although this work represents just a small step forward in our understanding of wearable abandonment, these

This work serves as a reminder that we must not conflate technical success with sociotechnical success. To transform a broken system into a functioning, people-oriented system, technical development must be accompanied by proportional social innovation. To do otherwise would be to forget Latour's caution: "an object that is merely technological is a utopia" (Latour, 1996).

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