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The Diffusion Dilemma in Innovation: Slow and Unequal Uptake of Low-emission Inhalers in the USA

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Abstract
This study examines the adoption of low-emission Inhalers versus traditional metered-dose inhalers (MDIs) in the U.S., using data from the Medical Expenditure Panel Survey (MEPS) from 2010 to 2021. Despite the environmental benefits of low-emission inhalers, their adoption has been slow and marked by socio-economic and racial disparities. Analysis reveals that patients below the poverty line are significantly less likely to use low-emission inhalers, as are patients who are uninsured, and patients who self-identify as Black—with all these gaps widening over time. The findings highlight the need for targeted policy interventions to address these disparities and enhance equitable access to environmentally friendly healthcare innovation. Future research should investigate pricing dynamics, out-of-pocket expenditures, and causal mechanisms behind these disparities. This study underscores the challenge of aligning environmental goals with health equity in healthcare innovation.

Keywords: Innovation; healthcare; low-emission inhalers; equity; greenhouse gas emissions

I. Introduction

As climate change accelerates, the focus on reducing greenhouse gas (GHG) emissions intensifies across various sectors, including healthcare. The U.S. healthcare sector contributes significantly to global GHGs, accounting for 4.6% of all emissions and representing the largest national contributor within the sector at 29% [1]. This concern is highlighted in international commitments such as Article 10 of the Paris Agreement, which underscores the importance of technological innovation and low-emission procurement in mitigating the environmental impacts of the health sector [2].

Among the technologies in addressing this environmental challenge are inhaled medications used by 25 million U.S. citizens suffering from asthma or chronic obstructive pulmonary disease

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(COPD) [3]. Traditional metered-dose inhalers (MDIs) use propellant gases to propel medication into a patient's lungs. These propellants are potent GHGs and have significant carbon footprints [4]. In contrast, "low-emission Inhalers" use a dry powder or a soft mist to diffuse the drug that can then be inhaled, offering an alternative with their significantly lower GHG profile. Low-emission inhalers have therefore the potential to deliver similar therapeutic benefits as MDIs without the use of harmful propellants [5].

However, the introduction of low-emission inhalers presents a series of critical dilemma in health policy. On the one hand, while these inhalers could lessen the health sector's carbon footprint, they may not significantly enhance individual health outcomes. Low-emission inhalers require that patients actively breathe the aerosolized drug instead of propelling it into a patient's lungs like MDIs do. Pulmonologists have already expressed concern that for specific subsets of patients—for example as children and older adults who lack the cognitive ability or motor skills to perform the correct inhalation procedure—there may be a trade-off between clinical benefits and ecological benefits [6] [7]. This paper is chiefly concerned with a second potential trade-off: the higher prices associated with new product patents on low-emission inhalers could exacerbate existing inequalities in healthcare access by socioeconomic status, insurance status, and racial or ethnic identity [8]. This equity dilemma is not new in innovation; namely, individuals in the bottom of the income distribution tend to benefit from innovations much later in time than individuals in other brackets [9].

This study utilizes data from the U.S. Medical Expenditure Panel Survey (MEPS) spanning 2010-2021 to explore the adoption dynamics of low-emission versus meter-dosed inhalers, with a focus on the socioeconomic factors influencing their uptake [10]. This approach marks a fundamental advancement from previous work, as it captures demographic and socio-economic indicators at the individual level rather than at the geographic level as most of previous work in this field has done. Using data at the individual level offers a more nuanced understanding of the equity implications in the adoption of new technologies. This is also critical to inform policies to promote access and utilization of green MDIs (inhalers using low-GHG propellants) when these become available.

Findings of this study indicate a slow but increasing adoption rate, with notable disparities based on race and socioeconomic status. For instance, individuals who self-identified as Black were found to be 3.5% less likely to adopt low GHG inhalers compared to those who are no black—a significant disparity given the 19% baseline adoption rate. Similarly, uninsured and economically disadvantaged individuals exhibited markedly lower adoption rates.

The widening racial and socioeconomic gaps in the adoption of low-emission inhalers underscore the urgent need for targeted policy interventions. By understanding the barriers to adoption and identifying effective strategies, policymakers can aim for a more equitable distribution of environmentally friendly healthcare technologies. Lessons from studying this medical device may be broadened to include the implications of incorporating other low-emission medical devices into the health policy agenda.

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Finally, studying low-emission inhalers offers an opportunity to examine a common dilemma in the adoption of health technologies; namely, that the high price of new innovations may take time to permeate across different societal groups, making the most disadvantaged groups the last beneficiaries of these innovations. Our paper, therefore, not only contributes to the literature on the environmental impact of the health sector by studying one specific technology but also explores the often-ignored topic of the equity implications of adopting new health innovations.

II. Empirical strategy and data description.

Our empirical strategy unfolds in three parts to analyse the adoption of low-emission inhalers and the demographic and socio-economic disparities influencing this adoption from 2010 to 2021.

We begin with a descriptive analysis to map the trends in the use of low-emission inhalers over the stated period. This analysis will provide a foundational understanding of the general adoption patterns and set the stage for a deeper exploration into the specific disparities and gaps.

In the second part of our empirical work, we conduct sequential econometric analyses [11] to examine the disparities in the adoption of low-emission inhalers among different demographic and economic dimensions such as race, insurance status, income level, and regional location. These analyses aim to identify statistically significant differences in adoption rates that may be attributed to demographic and socio-economic factors. This detailed segmentation allows for a nuanced understanding of the adoption patterns and potential disparities.

We focus on the following key comparisons:
- Racial identity: Comparison of adoption rates between patients who identify as Black and those who do not.
- Insurance Status: Differences in adoption rates between insured and uninsured populations.
- Income Level: Analysis of adoption trends respondents above and below the annual poverty line. Respondents are considered poor if their annual income was below the annual poverty line [12].
- Region: Examination of geographic disparities, with a focus on the South versus other regions.

In the final part of our empirical strategy, we employ econometric models to test whether the adoption gaps identified in Part II are closing or widening over time. This analysis will help us understand the dynamics of inequality in low-emission inhaler usage and evaluate the effectiveness of current policies and interventions.

In all empirical estimations in part II and part III, we add as control covariates gender, age (individuals older than 18 years of age), marital status, and employment status. We also include fixed effects at the region level. Following standard practice in econometric analysis, we imputed missing values in the control covariates using the mean of the variable and added the respective dummy variables as controls. In cases where values of the relevant outcome variables

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were missing, these observations were excluded. We included all relevant observations at the household level and corrected the standard errors to account for multiple observations within the same household. Finally, we discussed the results using robust standard errors.

II.1 Data Description

The data for this study come from the U.S. Medical Expenditure Panel Survey (MEPS) spanning from 2010 to 2021. MEPS is a set of large-scale surveys of families and individuals, their medical providers, and employers across the United States. What makes MEPS particularly valuable for this study is its rich detail on health services that capture the use, frequency, and type of health care services including prescription drug use and expenditures [13]. Additionally, MEPS provides comprehensive data on health insurance coverage and a broad range of economic and demographic information at the individual and household levels [14].

We used information from the Food and Drug Administration (FDA)'s Orange Book Database of Approved Drug Products to identify the study drugs of interest: inhaled medications to treat asthma and COPD [15]. The Orange Book lists several drug characteristics including proprietary and non-proprietary name, route of administration, commercial formulation (dosage form), and strength. We extracted all drugs recorded in the Orange Book as having an inhaled route of administration. From this list, we excluded discontinued and over-the-counter drugs. Next, we identified the drugs administered by metered spray, metered aerosol, powder, or metered powder form. This ensured that drugs inhaled through other mechanisms, such as drugs requiring nebulization and gases used in anesthesia were excluded from the study. Lastly, we excluded drugs that treated other conditions but not asthma or COPD (such as inhaled levodopa to treat Parkinson's Disease). This search resulted in a total of 78 drugs of interest, which constituted the sample of drugs in this study. This search was performed in February 2023. Using the Orange Book information, we categorized the inhaled drugs of interest between drugs containing propellants (metered aerosol drugs or MDIs) and drugs that did not contain propellants (powder drugs, metered powder drugs, and metered spray mist-inhaler drugs, or low-emission inhalers).

In this study, we included all MEPS participants aged 18 and above who reported using at least one medication in our list of inhaled drugs used to treat asthma or COPD. For each included participant, we extracted information on the drug utilized (drug proprietary and non-proprietary name, dosage form, and strength) as well as on the participant's characteristics (race, insurance status, income level, and regional location). We code each relevant control variable according to standard categories used in the literature when researchers used the MEPS database [16].

III. Results

Table 1 describes the sample used in our empirical work from 2010-2021. In our sample, 22% of the respondents identify as Black, 2.9% are uninsured, and 58% report an annual income below the poverty line. The respondents have an average age of 58 years, with 61% being female and 66% reporting that they are married. Lastly, 14.44% of the sample report having 9 or fewer years of education.

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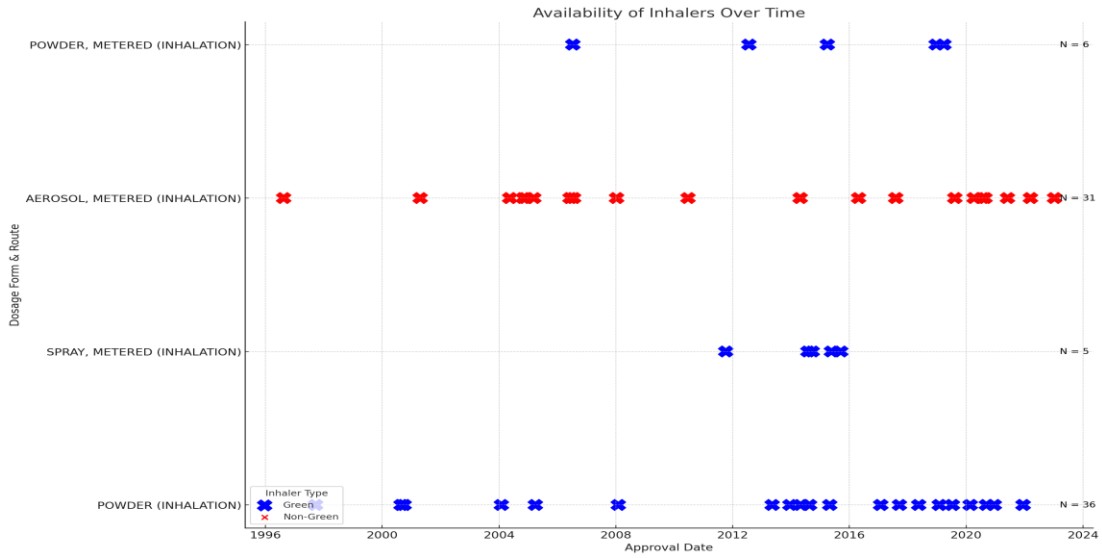
Table 1.- Descriptive Statistics

Variables	Mean	Standard Deviation	N
Green Inhaler usage (1: green inhaler; 0:otherwise)	0.1925	0.3943	107,436
Race (1: Black; 0: otherwise)	0.2205	0.4146	107,436
Insurance Coverage (1: no coverage; 0: any coverage)	0.0298	0.2068	107,436
Poverty Status (1:poor; 0: non-poor)*	0.5801	0.4935	107,436
Age	50.93	21.61	107,436
Sex (1: female; 0: male)	0.6089	0.488	107,436
Marital Status (1=married; 0= otherwise)	0.6622	0.473	107,436
Education Level (1: 9 years or less; 0: 10 years or more)	0.1444	0.3515	107,436

* Participants were considered poor if their annual income was below annual poverty line.

The market dynamics for traditional metered-dose inhalers (MDIs) and low-emission inhalers have shown significant fluctuations over the past decade. Since their introduction in the 1990s, the market for low-emission inhalers has expanded significantly. By 2004, the market offered around eight options of powder inhalers, which increased to 24 different options by the end of 2020. Despite this growth in availability, the prices of low-emission inhalers have remained higher than those of MDIs, leading to increased out-of-pocket costs for consumers. The availability trends of low-emission inhalers over the past two decades are illustrated in Figure 1.

Figure 1- Availability of Low-emission Inhalers during 1996-2024



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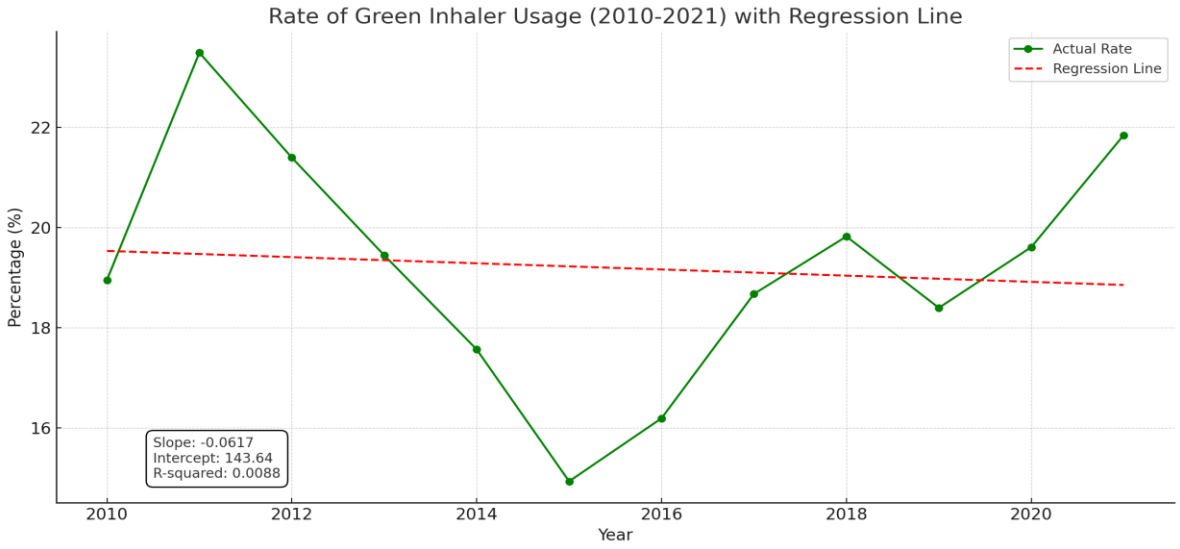
After establishing that the market for low-emission inhalers has been fluid, our analysis next turns to the penetration of these devices. As depicted in Figure 2, the data indicates a steady penetration post-2015, although the overall penetration over the examined period has been slow—the average rate for the full period is 19.5%, and it fluctuates between 16% and 22% during the whole period.

Figure 2. Market Penetration of Low-Emission Inhalers 2010-2021



Our descriptive analysis of market penetration reveals three distinct patterns. Firstly, individuals below the poverty line are consistently less likely to adopt low-emission Inhalers compared to their wealthier counterparts, with the gap remaining constant over the last five years. The unadjusted correlation between poverty and the probability of using a low-emission Inhaler is -0.089, while the correlation with respect to income is 0.065. Secondly, individuals who identify as Black are less likely to adopt low-emission inhalers than those who do not, and notably, this gap has widened over time. Thirdly, uninsured individuals are less likely to adopt low-emission Inhalers compared to insured individuals, with this gap also widening over time. Figure 3 displays the unadjusted correlations between the adoption of low-emission Inhalers and various socio-economic variables.

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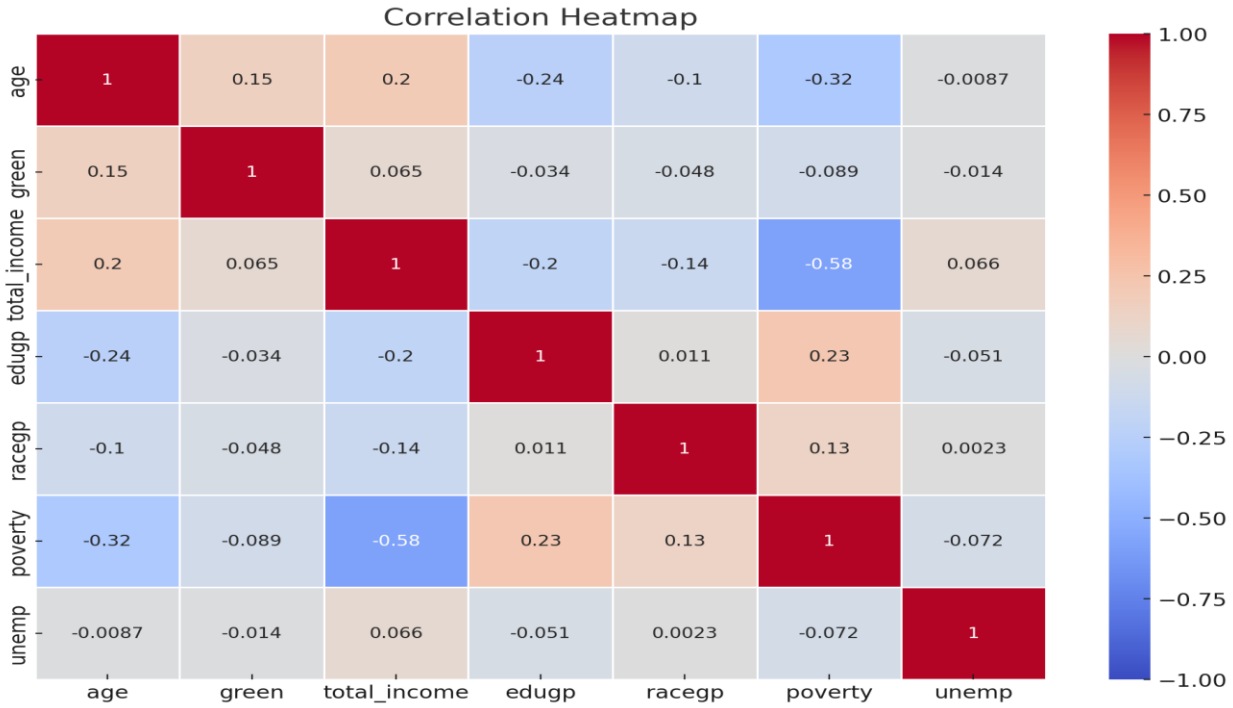
Figure 3. Unadjusted correlation between demographic and socio-economic factors and use of Low-Emission Inhalers



The regression analysis underscores these disparities: after controlling or relevant covariates, poor individuals are 4% less likely to adopt low-emission inhalers compared to non-poor individuals, a statistically significant effect at $p<0.05$. Similarly, uninsured individuals are 6% less likely to adopt low-emission inhalers, significant at $p<0.03$. The regression model also reveals a disparity for Black individuals, with a significant effect size. To maintain clarity, only the coefficient for uninsured status is shown in Table 2, though full results are available upon request.

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Table 2. OLS Estimates of the Association between Poverty and the Adoption of Low-Emission Inhalers.

Variable	Model 1	Model 2	Model 3
Coefficient (Poverty)	-0.0434	-0.0433	-0.0411
Standard Error	0.0034	0.0034	0.0031
P-value	<0.001	<0.001	<0.001
R2	0.0210	0.0260	0.0289
Constant	0.1782	0.2023	0.2181
Sample Size	102,663	102,663	102,663

Model 1: controls for age, gender, and time fixed effects. Model 2: add marital status, geographic areas and time fixed effects. Model 3: adds education, occupation to the rest of the variables.

Using these model estimates, one could further investigate the role of differences in racial disparities in adoption. In other words, once socio-economic disparities are eliminated, how much of the remaining gaps are attributable to racial differences? An initial analysis suggests that closing income differences (as determined by the poverty line) would eliminate around 37% of the gap in the adoption of low-emission inhalers between Black individuals and the rest of the sample. This underscores the significance of endowment effects but also reveals the persistent impact of racial disparities, even after levelling the playing field. Future research should approach this problem using decomposition methods, such as the Oaxaca-Blinder decomposition, to pinpoint the relevance of endowment disparities and distinguish them from the effects of differences in coefficients and unobservable characteristics —such as preferences toward certain inhalers and initial health status.

Lastly, our convergent/divergent analysis using indicator variables for year, race and their interaction indicates that the disparities in adoption rates by race, insurance status, and socioeconomic status, as well as those in poverty, is not narrowing but rather widening over time. This is visually represented in Figure 4, showing the relevant regression coefficients in the case of the race indicator. Similar pattern emerges when looking at poverty and uninsured individuals.

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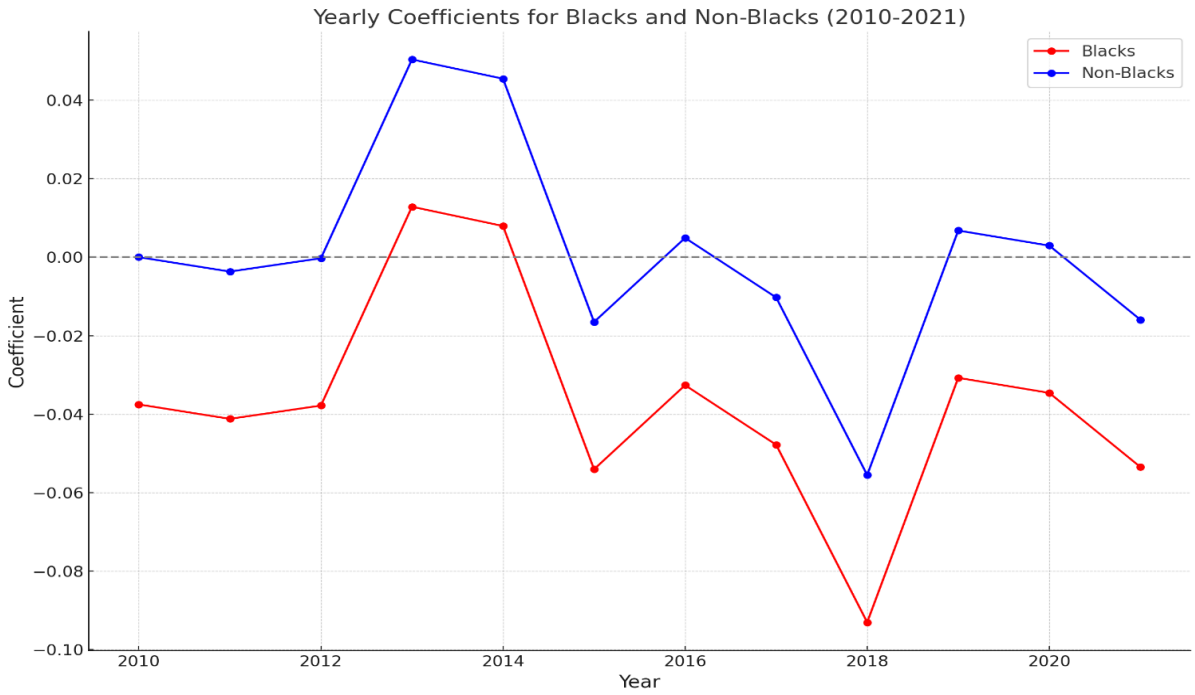
Figure 4. Converge/Diverge Econometric analysis by race



Taken together all results, out analysis of low-emission Inhaler usage over the past decade reveals a pattern of fluctuating adoption rates, with a slow but gradually increasing uptake in recent years. Notably, individuals who identify as Black have a 3.5% lower likelihood of adopting low-emission Inhalers compared to those who do not, which is both statistically significant and meaningful given the 19% baseline adoption rate. Similarly, uninsured individuals and those living in poverty have lower adoption rates by 4.1% and 4.0% respectively compared to their insured and wealthier counterparts. These effects are significant in magnitude and underscore the persistent socio-economic and racial disparities in the adoption of low-emission Inhalers.

The widening gaps in adoption across socio-economic and racial lines raise important policy considerations. Despite the increase in options and a general trend towards greater adoption, the barriers to accessing low-emission inhalers remain significant for disadvantaged groups. This trend suggests that without targeted interventions, the benefits of low-emission and potentially healthier inhaler technologies will likely continue to elude those most in need, further entrenching existing health disparities. Similar results have been reported in the use of other devices, such as insulin pumps [17], hearing aids [18], and home dialysis machines [19].

IV. Discussion

This study documents the slower adoption of low-emission environmentally friendly inhalers among disadvantaged groups, emphasizing the key balance that must be struck between environmental initiatives and equity considerations in the healthcare sector. As analysts consider

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the trade-offs involved in implementing environmental policies, it becomes apparent that there is a significant need for public policies that incorporate compensatory measures. These measures are vital as the urgency to reduce greenhouse gas emissions intensifies across various sectors, including healthcare. This case study underscores the importance of designing policies that not only advance environmental goals but also promote social equity, ensuring that all segments of the population benefit from innovations in health technology.

The study shows the persistent and widening disparities in the adoption of low emission inhalers across racial and socio-economic groups, highlighting a clear need for targeted policy interventions and continuous reassessment. Despite the broad availability of low emission inhalers, their adoption has been slow and uneven, with significant gaps particularly affecting Black, uninsured, and economically disadvantaged populations. It is possible that some of the populations that had lower adoption rates of low emission inhalers might not have been good candidates to take those drugs in the first place due to their inability to perform the correct inhalation mechanism to absorb the drug. If the groups with lower adoption – Black individuals, uninsured, and economically disadvantaged groups – were more likely to represent children, older adults with dementia, or other population groups who depend on a pressurized inhaler to propel the drug into the lungs due to incapacity of performing the correct breathing procedure to benefit from low emission inhalers, then the lower adoption rates among these groups would be not necessarily indicative of a problem or a gap in access. This study excluded children and adolescents, mitigating the possibility that children and adolescents were driving the slower adoption of low-emission inhalers among key socio demographic groups. However, we could not clearly differentiate between adults with and without the capacity to perform the adequate breathing techniques to appropriately use the low emission inhalers. We assumed that all adults would be capable of appropriate breathing techniques and therefore would be eligible for the low emission inhalers. This should be the focus of further research. Nevertheless, these findings underscore the urgency of designing and implementing strategies that address these disparities directly.

One critical area for policy intervention is the development of targeted measures to address the racial disparities observed. For instance, community-driven initiatives and structural competency training for healthcare providers may help bridge the trust and knowledge gaps that contribute to the lower adoption rates. Furthermore, continuous monitoring and reassessment of low-emission Inhaler adoption trends are essential to ensure that interventions remain effective over time and adapt to changing markets and healthcare landscapes.

In Europe, particularly in Sweden, the adoption of low-emission inhalers has been faster than in the U.S., possibly contributing to these countries' comparatively better health outcomes. Sweden has implemented extensive environmental policies and public awareness campaigns that have facilitated the widespread use of low-emission inhalers. Studies have shown that Swedish patients experience better adherence and clinical outcomes with low-emission inhalers, attributed to the robust support systems and subsidies in place [20]. Additionally, Sweden's comprehensive healthcare system may play a role in ensuring equitable access to these inhalers, minimizing

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disparities seen in other regions [20]. France has also seen substantial success in promoting low-emission inhalers through coordinated healthcare policies and subsidies [22] [23]. Furthermore, in South Korea, the government has actively promoted the use of environmentally friendly inhalers through national health policies and public health campaigns. South Korea's approach demonstrates the effectiveness of integrating environmental considerations into healthcare policies and can provide insights to enhance the adoption of green health technologies [24].

Future research should focus on dissecting the economic underpinnings of low-emission inhaler markets, including the trajectory of list prices, net prices, and rebates, as well as studying out-of-pocket expenditures and the determinants of switching behaviors. Additionally, there is a need to explore the causal mechanisms behind observed disparities and the role of potentially omitted variables and clinical implications, which could provide deeper insights into how best to address these issues.

On a broader scale, policy efforts should aim to promote widespread adoption of low-emission inhalers through awareness campaigns and by addressing socio-economic barriers. Economic incentives, such as subsidies or providing low-emission inhalers at discounted rates for underprivileged groups, could significantly enhance access. Expanding insurance coverage to include specific plans that cover low-emission inhalers could also play a pivotal role in increasing adoption rates. Facilitating generic entry for low-emission products – which is often a challenge due to the extensive patent protections that are typically placed on inhaled drugs by the branded manufacturers – could also help increase competition, helping to lower prices and increase access.

This study, while extensive, is not without limitations. The reliance on self-reported data from the MEPS may introduce biases in reporting and recall. Additionally, the cross-sectional nature of our analysis identifies associations but cannot confirm causality. The potential for omitted variable bias exists as unobserved factors could influence the results. Finally, we did not observe individuals who had the need for an inhaler but did not use one due to affordability challenges or other barriers to access. The unmet need for inhalers to treat asthma and COPD, particularly differentiating between the unmet need for MDIs and low-emission inhalers, should be the focus of future investigations. These limitations highlight the need for cautious interpretation of the findings and suggest areas for further methodological enhancements in future research. Lastly, by only studying questions of race and racism in terms of anti-Black racism, this study can only approach a very small part of how racial disparities intersect with environmental health in this case. Nonetheless, the findings are still striking and valuable for policymaking.

By addressing these disparities and barriers comprehensively, it is possible to not only improve public health outcomes but also to take meaningful steps towards environmental sustainability in healthcare practices. The convergence of health equity and environmental impact in the context of low-emission inhalers presents a unique opportunity to align public health interventions with broader environmental goals, thereby fostering a healthier population and planet.

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