

Unveiling the association between health, poor housing, and energy affordability

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Abstract— Poor housing conditions can have a profound impact on individual’s health status and wellbeing. This study addresses the case of Portugal, using data from the European Union-Statistics on Income and Living Conditions (EU-SILC) microdata. It resorts to a dynamic panel approach, to estimate the likelihood of having poor health and its prevalence, depending on living conditions, socioeconomic status, and energy-poverty indicators. Research findings show the relevance of living conditions and socioeconomic conditions upon health condition. Furthermore, by exposing adverse effects of inefficiency, the paper’s contributions ultimately aim to support and promote the adoption of energy efficiency policies that contribute towards the improvement of living conditions and health in Portugal, as well as other European countries. Thus, a foreseen policy implication is that, aspects such as poor health and energy poverty should be considered as additional eligibility criteria for housing energy efficiency program, besides low income.

Index Terms-- Portugal; EU-SILC microdata; energy poverty; panel data analysis

I. INTRODUCTION

It is a widely accepted belief that exposure to poor housing conditions, such as thermal discomfort (too cold or too hot) and damp, exerts adverse impacts on physical and mental health. Yet, several studies have emphasized that the improvement of indoor temperatures has a positive association with better health (e.g. [1], [2]), and energy efficiency measures.

The assessment of housing energy efficiency program in England, showed that greater thermal comfort and reduction of fuel poverty were significantly correlated with lower stress levels and improved health [1]. A review performed by Fisk et al. (2020) [2] featured the influence of energy efficiency retrofits on indoor environmental quality conditions and self-reported thermal comfort and health, with consistent improvement of reported thermal comfort and general health after retrofits. Energy efficiency improvements are not only

associated to health improvements of cold homes but also during heat events [3]. Improvements on adequate heating, ventilation and water supply have been associated with improvements of respiratory, mental health and quality of life outcomes [4]. Yet, the quantification of the relevance of its effects on health is challenging ([5][6]), despite potential socioeconomic benefits. According to Velux Group (2018) [7], 84 million Europeans (1 in 6 people) report living in poor housing conditions, from this universe, ‘73% view improved wellbeing as a driver for housing renovation’ pp. 9.

At national level, the adoption of these energy efficiency measures in the Portuguese context, requires policy incentives, for economic reasons, since household income is insufficient and prevents the investment and adoption of high efficient alternatives by local communities [6]. The study of energy efficiency-related health impacts, in engineering fields, has been focused (e.g. [8],[9]), but has grown to a relatively lesser extent than other energy efficiency-related concerns, such as climate change. Meanwhile, despite being severely affected by energy poverty, this issue is still somewhat unrecognized in Portugal [10]. OPENEXP (2019) study, based on a composite indicator- Domestic Energy Poverty Indicator (EDEPI)- has ranked Portugal among the worst countries in the efforts to alleviate energy poverty, in a cross-country comparison at EU level (25th place in total of 28 countries). In common, the lagging countries shared a lower GDP per capita than the EU average and recent regulations on building energy performance and energy poverty policies [11]. In Portugal, building regulations regarding energy performance, were introduced only in the 1990s, implying that most of the building stock prior to this date is ‘obsolete from an energetic point of view’ [12]. Also, national energy poverty concerns are relatively recent with a long-term national strategy to tackle energy poverty 2022-2050 under public consultation, in March 2023 [13].

Therefore, the need to contemplate the relationship between the housing-energy-health trio has been emerging, with the recognition that poor housing and energy poverty could harm householders’ health and wellbeing (see [14], [15]). The

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novelty and added value of the present research is twofold: (1) promoting a longitudinal analysis of the impacts upon health from the exposure to poor or energy inefficient housing; (2) further improving the assessment of the relation between housing conditions and health status, by considering the energy use.

Given the abovementioned context Portugal, presents itself as an interesting case study. In the coming sections, the research methodology adopted and model specification are described in Section II. In Section III, the results of the empirical analysis are provided and in Section IV the paper ends with conclusions and policy implications.

II. METHODOLOGY

In the present section, we proceed by presenting the database, the dataset, and the modelling approach. The study contributes thus to focus on the relevance of addressing poor/inefficient housing upon health, based the most recent four waves of EU-SILC (European Union Survey on Income and Living Conditions, Eurostat User Database) panel data (2014-2017). It seeks to answer the following research questions:

RQ1: Do householders who experience continuous cold and damp problems present a higher prevalence in self-rated poor health?

RQ2: How do other contextual factors, such as aging, or energy poverty affect the prevalence of poor health status?

Framed by the abovementioned research questions, the objective of the study was to assess householder's perception of poor health status, when exposed to living conditions. It was considered important to ascertain if the perception of poor housing conditions (e.g. damp walls and rot windows) and the perception of thermal discomfort (inability to keep warm) affect the reporting on poor health by householders. Additionally, the influence of contextual factors, such as age or gender and education is also established, in relation to reporting health status.

This methodology presents the advantage of the use of a single database, that includes both living and socioeconomic conditions, providing a statistically significant sample for the modelling approach. The possibility to study the profiles of individuals over time, is the main reason for the use of this modelling approach. The period of time used is aligned with prior studies that focus on the assessment of persistent trends (e.g. [16])

A. Database and dataset

The present work resorts to the European Union -Statistics on Income, Social Inclusion and Living Conditions (EU-SILC) database, in its most recent four-wave period, between 2014 to 2017. This survey database was launched in 2003 and currently covers all EU countries, aiming at collecting timely and comparable cross-sectional and longitudinal microdata on income, poverty, social exclusion and living conditions [17].

Therefore, taking into consideration the abovementioned database characteristics: we restrict the sample to persons aged 16 and over, who were present in all survey waves and have no missing information regarding variables of interest at household or individual level. A similar strategy has been used

previously by [18] to improve comparability and to avoid potential subjective bias [19].

The application of the filters on the initial dataset at individual and household levels, has prompted the exclusion of respondents, which contributed to a significant decrease in the size of our sample over the four-wave period, resulting in a balanced panel (N=6400), as the final dataset. Additionally, this sampling design based on exclusion of incomplete information over the years, has been used in prior studies resorting to EUSILC (e.g.[20]). It is important to note that the information in the database is about self-reported perception. A summary of main variables is presented in Table I (see V. Appendix).

Table I presents the balanced sample of respondents (nT=6400), over a four-wave period (T= 4 years). In our sample, 55% of the respondents are female and 46% are male. A majority of the individuals report a good health status (83%). The share of individuals reporting suffering from chronic conditions is 44%. Meanwhile of those living in poor housing conditions, 29% reported being exposed to damp walls/floor and rot windows.

Similarly, in the sample the share of householders unable to keep the house warm is 24%. Whereas 93% expressed not experiencing difficulties in paying for utility bills. Regarding socioeconomic explanatory variables, the share of elderly respondents the mean age is approximately 53 years old for the overall sample. Most of these respondents (58%) are married, with medium -post primary- education (52%); have an intermediate income level (3rd quintile) and live in detached houses (39%), located in urban/peri-urban areas (65%). These variables served as input for the subsequent modelling approach.

C. Model specification

The perception of the current health status often depends on its prior or past perception, given that chronic health conditions may persist over time or that the recovery period from a given illness may extend over time [21]. Therefore, the use of a modelling approach that takes into consideration such specificities, i.e. current and past health status information, is warranted.

The present study resorts to a dynamic panel approach, to model the present health status perception as a function of previous or past health status perception. This approach accounts for state dependence, i.e. that a given householder that reports a given health status (good or poor) at a certain period in time, is more likely to persist or report the same health status in the following period. Conventional panel data models (fixed and random effects) do not account for these dynamics, namely, do not consider in their formulation the use of previous and subsequent periods. For this purpose, a dynamic probit model with Wooldridge approach was adapted (see [22]).

This model considers a lagged and initial dependent variable among the regressors. The lagged dependent variable is used to assess the presence of state dependence. If the lagged dependent variable (past health status) affects the independent variable (current health status), even after controlling for other

explanatory variables that influence the reported health status, there is state dependence [23]. The inclusion of the initial variable as a regressor in the model, accounts for the unobservable variables that are correlated with the outcome and are likely to be correlated also with the lagged dependent variable (see [23],[24]). This model has been recently described by [24] and [16], following the model specification in equation (1). Let y_{it} designate a dependent variable, for individual i ($i = 1, \dots, N$) at time period t , the formulation in equation 1, can be written as indicated in equation (1).

$$y_{it}^* = x'_{it}\gamma + \rho y_{i,t-1} + c_i + u_{it}, \quad i = 1, \dots, N; t = 1, \dots, T \quad (1)$$

$$y_{it} = 1(y_{it}^* > 0)$$

Where x_{it} are assumed to be strictly time-varying explanatory variables, conditional on c_i , the individual-specific unobserved effect, γ and ρ parameters are the regression coefficients for the explanatory variables and the lagged dependent variable ($y_{i,t-1}$), and u_{it} is the error term. y_{it}^* captures the latent outcome variable that expresses the odds of a given individual (i) experiencing a particular health status at a given time (t), as a function of a set of explanatory variables x_{it} . In the Wooldridge approach, the use of a Mundlak correction addresses the assumption of independence between the covariates and the error term by considering the individual means each of the time varying variables [23]. The individual-specific unobserved effect c_i , can be modelled according to [25] in equation 2.

$$c_i = \alpha_0 + \alpha_1 y_{i0} + \alpha_2 \bar{x}_i + \alpha_3 x_{i0} + a_i, \quad a_i \sim N(0, \sigma^2) \quad (2)$$

Where y_{i0} represents the initial value of the outcome variable and \bar{x}_i stands for the within-unit averages of time-varying explanatory variables $\bar{x}_i = 1/T \sum_{t=0}^T x_{it}$, where the averages consider all periods $t = 0, \dots, T$, and finally a_i is a time-constant error term ([26],[27]). The individual-specific unobserved effect (c_i), refers to unobserved heterogeneity i.e. to a set of unmeasured individual effects which can be associated with a given health status, regardless of the previously reported health status (e.g. chronic conditions or poor housing), in contrast with the state dependence.

This model includes the within-unit averages or 'Mundlak-type variables' that were also adopted by [28] to overcome the loss of sample size from conventional models and approximate the random effect panel model to a fixed effects specification, under a logit model formulation. The final latent index model is obtained, as formulated in equation 3.

$$y_{it}^* = x'_{it}\gamma + \rho y_{i,t-1} + \alpha_0 + \alpha_1 y_{i0} + \alpha_2 \bar{x}_i + \alpha_3 x_{i0} + a_i + u_{it}, \quad (3)$$

Where the coefficient (ρ) of the latent variable $y_{i,t-1}$ represents health status state dependency. Another advantage mentioned by [27] is that the addition of initial value explanatory variables $\alpha_3 x_{i0}$ as additional regressors addresses bias for short panels. This model is estimated with `xtpdyn` command, developed by [26], using Stata software.

Resorting to the use of a post-estimation option of this model (`probat`), the transition dynamics or patterns of poor health are exemplified for living conditions and socioeconomic explanatory variables. The additional statistics include entry, exit and persistence probabilities, average duration of poor health spell and steady state estimates. The specific profiles are defined by additional statistics computed according to equations (4) to (6), following [26] specification:

Exit probabilities ($Pr(0|1)$), are derived from the persistence estimates ($Pr(1|1)$), and are computed as indicated in equation (4).

$$1 - Pr(1|1) \quad (4)$$

While $Pr(1|1)$, denotes the probability of being in poor health in the present year, having been in poor health status in the prior year, $Pr(0|1)$ denotes the opposite, the probability of not being in poor health in the present year, having been in poor health in the prior year. The poor health spell is a cycle, it is indicative of the average amount or length of time an individual could spend in poor health. The mean or average duration of the poor health status spell is given by equation (5).

$$1/Pr(0|1) \quad (5)$$

Finally, the steady-state probability or the expected proportion of time an individual displays poor health status is computed as presented in equation (6).

$$Pr(1|0)/\{Pr(1|0) + Pr(0|1)\} \quad (6)$$

The steady state probability is indicative of the time spent in poor health status, under a (ideal) scenario in which all covariates remain fixed. It should be noted that equations (5) and (6) are computed under the steady state assumption $x_{it} = x_i$ for all t and stable entry and exit probabilities ($Pr(1|0)$ and $Pr(0|1)$), enabling to extend the comparisons between profiles giving a 'long-run' insight, even when working with relatively short timeframes [29]. All else remaining the same, it is possible to determine, on average, the time spent in $y=1$ (in poor health status), for a given timeframe or observational window.

Overall, the panel data analysis studies the persistence and dynamics of poor health status for a subsample of anonymized households between the years 2014 and 2017.

Xtpdyn modelling approach specifies both time invariant (e.g. gender) and time-varying (e.g. marital status) independent socioeconomic variables. Post-estimation options (`probat` command) were used to portray the dynamics for specific socioeconomic variables such as age and thermal discomfort.

III. RESULTS AND DISCUSSION

The results for the dynamic panel model and post-estimations are presented in this section. In Table II the dynamic panel model results are disclosed. Given that the focal interest is to assess the association between cold/thermal discomfort, damp and self-report health, taking into consideration other contextual factors such as energy poverty and age. As established in the methodology section, the present work, namely post-estimation results focus on specific relationships that consider only most significant regression

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results, namely regarding age and energy poverty. Even though it is recognized that energy poverty is a multi-dimensional concept, we follow the proxy earlier established in the methodology section, and not the broader concept of poverty itself.

TABLE II. DYNAMIC RANDOM-EFFECT MODEL COEFFICIENTS

	Variables	Coefficients	Std. error (SE)
Explanatory variables	Lagged general health (L.genhealth)	0.488***	0.128
	Age	0.331***	0.006
	Utility bills	0.340**	0.162
	Damp and rot	-0.056	0.091
	Thermal discomfort	-0.170*	0.099
Initial value	General health_0	1.464***	0.187
	Utility bills_0	0.020	0.195
	Damp and rot_0	-0.051	0.133
	Thermal discomfort_0	-0.081	0.122
Within-unit average	m_Utility bills	-0.298	0.426
	m_Damp and rot	0.261	0.287
	m_thermal discomfort	0.544*	0.284
Note: ***p < .01, **p < .05, *p < .1, respectively			

In Table II, the interpretation of each coefficient is relative to its reference category. The initial value is generated for the dependent or other explanatory variables and assumes the value for the first time period (year) in which the household is observed, it is denoted as ‘variable_0’. The variables denoted ‘m_variable’ represent the within-unit average of a given time-varying independent variable (\bar{x}_i).

The first coefficient in Table II is the lagged dependent variable (L.generalhealth), it assumes the values of self-reported health status at previous period (t-1), capturing genuine state dependence. Obtained results seem to suggest a positive and significant state dependence which denotes that the chance of reporting poor health increases even after controlling for the initial value (y01) and other covariates. This means that individual’s prior health status does condition the individual’s next health status report.

As a result, the lagged dependent variable ($\rho y_{i,t-1}$ in equation (3)), denotes the presence of poor health persistence.

The initial value for general health (General health_0), captures unobserved heterogeneity ($\alpha_1 y_{i0}$, in equation 3)), its statistical significance and positive sign indicates its association with unobserved factors correlated with the outcome, contribute to increase poor health.

In fact, it captures the largest amount of unobserved heterogeneity correlated with poor health (1.464), when comparing with initial values from other explanatory variables ($\alpha_3 x_{i0}$, in equation 3)). This result is consistent with prior studies (e.g. [42]) that has identified Portugal with highest persistence for limitations posed by chronic health, among EU-countries.

The dynamic panel model results, illustrated in Table II, emphasize the relevance of the issue of thermal discomfort from living in cold homes in Portugal, which is consistent with

prior research (see [30], [31]). However, its impact on health seems to be undermined by the householders.

According to [32], Portugal is amongst the countries in the European Union that presents higher shares of poor housing conditions namely thermal discomfort and damp walls but with the lower shares of self-reported poor health. On the other hand, energy poverty indicators, such as arrears on utility bills, seem to denote that when people are faced with being cut-off from basic energy services, poor health reports seem to increase. Obtained results seem to support [33] view and extend it to health concerns. This means that even though householders suffer from thermal discomfort, they may not realize its impacts on health, enduring it and therefore undermine its report.

Alternatively, disconnection from energy services, as a result of arrears on utility bills, might trigger the report of the negative effects of energy poverty on health. The transitions dynamics, i.e. the patterns in and out of poor health over time, the expected poor health spell duration and steady state probability seem to convey this perspective, as illustrated in Table III, that focus post-estimation results.

The profile for householders suffering from thermal discomfort and age, as illustrated in Table III, based on equations (4 to 6).

TABLE III.. HOUSEHOLDER PROFILE

Profiles:	Thermal discomfort	Thermal comfort	18 years old	30 years old	65 years old	Arrears on utility bills **	
						yes	no
Entry rate Pr(1 0)	0,11	0,13	0,02	0,03	0,13	0,09	0,13
Exit rate Pr(0 1)	0,84	0,81	0,96	0,94	0,79	0,86	0,82
Persistence rate Pr(1 1)	0,16	0,19	0,04	0,06	0,21	0,14	0,18
Steady state probability		0,14				0,10	0,13
*	0,12		0,02	0,03	0,14		
Mean duration of spell	1,20	1,23	1,04	1,06	1,26	1,17	1,23

*Proportion of time in y=1; **proxy for energy poverty

Based on the proposed acceptance of thermal discomfort, householders might tend to report less poor health contributing for a low entry probability in poor health status, as illustrated in Table III. This means that people even though experiencing thermal discomfort, could downplay and disregard it, which could inadvertently lead to misreporting its impacts. This possibly means that people experiencing poor housing conditions, in the presence of thermal discomfort for large periods of time, have a different health perception than those experiencing thermal comfort for large periods of time, becoming less prone to consider themselves in poor health than their counterparts. This perspective would explain the unexpected reduction in entry probability (0.11 and 0.13) and increased exit probability (0.84 and 0.81), as well as lower persistence, duration of poor health spell among those experiencing thermal discomfort in contrast to those experiencing thermal comfort. These results might denote an underlying possible gap of knowledge between health impacts of poor housing, its main causes and possible alternatives to address them.

Regarding socioeconomic background, aging seems to significantly increase the chances of facing poor health. This result is expected and consistent with previous studies. For example, with increasing age, the likelihood of incurring in multiple chronic disease also increases, making this issue a challenge nowadays [34]. Therefore, older people could be considered amongst the most vulnerable group to the health risks of poor housing, given their time spent indoors and the propensity to develop non-communicable diseases.

From Table III, it is possible to see that age stratifies the risk of reporting poor health. The entry rate increases with increasing age, while exit rate decreases with increasing age. Similarly, and as expected, the persistence rate, the steady state probability and mean duration of poor health spell also tend to increase. This means that all else remaining unaltered in the model, the steady state probability or proportion of time spent in $y=1$ (i.e. in poor health status) will increase on average from 2% at younger ages to 14% at older ages, over a four year timeframe.

An analysis of obtained results emphasizes the similarity between thermal comfort and the profile for the elderly, in terms of poor health dynamics. The similar values might imply that as one ages, health tends to deteriorate and poorer health status might be reported, regardless of the ability to keep warm (thermal comfort). However, the comparison of steady state statistics, greater in thermal comfort (0.14) than arrears on utility bills (0.10) and thermal discomfort (0.12) profiles, seem to confirm that people might be misreporting their health status (over-reporting in the case of thermal comfort and under-reporting in the case of thermal discomfort).

Overall obtained results seem to emphasize the relevance of housing and energy related factors, in reporting health status and the need for residents to further be aware of these interconnections that are complex and often multidisciplinary and that require monitoring over time. It should also be noted that, the dataset from the present study uses full wavelength available, allowing to follow an individual over the years. Yet, the dataset in study still predates the year 2021, from which EU-SILC design was extended up to 6 years waves, on a voluntary basis, to improve its analytic potential [35], which could be seen as a limitation for the present study.

IV. CONCLUSIONS

This study aimed to contribute to a better understanding of poor housing and health dynamics at country level, using the case of Portugal. In order to do this, this research resorts to a dynamic modelling approach, that allows to establish a profile of poor health, namely the persistence and average duration of a poor health cycle.

The relevance of living conditions and socioeconomic conditions is confirmed, both for thermal discomfort, age and utility bills. However, only the latter contributes to increase poor health reporting. Surprisingly, experiencing thermal discomfort (inability to keep the house warm), seems to decrease the likelihood of reporting poor health. This result is unexpected and should be confirmed by other independent studies, as it would have relevant policy implications.

Results may denote that people experiencing thermal discomfort underestimate and misreport its health impacts. This might entail an acceptance and lack of awareness from people

suffering from energy poverty, regarding the potential health impact from thermal discomfort. This perspective is further corroborated by the effect of energy poverty on health, with householders reporting poor health only in extreme conditions, when facing potential disconnection from energy services. Research findings corroborate Portugal's status within EU's landscape, since along with Lithuania, Portugal has been targeted among the countries where the need for building stock and energy efficiency upgrades is required to address the issue of 'more households with arrears on energy bills with trouble keeping warm', in a clear contrast with Croatia and Slovenia, where building stock's thermal comfort is less at the basis of energy poverty issues [36].

Obtained results also denote the need to further explore how the combination of poor housing conditions and energy poverty potentially affect mental health, particularly in the context of increasing energy prices. For people over 65 years of age, there could be health implications, such as increasing visits to health practitioners, as a result of physical and mental health deterioration [37].

Additionally, results show that thermal discomfort and aging seem to be equally relevant drivers for poor health. The development of policies to deal with thermal discomfort while decreasing the emergence of adverse health effects, particularly for vulnerable population segments such as elderly and energy poor, is crucial given the demonstrated cumulative effect of age and the extent of the energy poor issue in Portugal. Furthermore, the inclusion of these aspects into energy and housing policies would contribute to better establish target groups, prioritize action, and develop solutions for energy and housing that improve health and wellbeing of vulnerable groups. Additionally, the use of digital solutions, regarding energy management, such as demand response approaches, could further contribute to improve household energy efficiency with greater advantages for vulnerable population segments (by increasing comfort and energy affordability, while decreasing energy consumption).

Thus, a foreseen policy implication is that, aspects such as poor health and energy poverty should be considered as additional eligibility criteria for housing energy efficiency program, besides low income. Overall, modelling results denote, as main policy implications for energy and housing development planning in Portugal, the pressing need for health policies to contemplate housing conditions, as well as, in tandem, the need to quantify positive health impacts as energy efficiency benefits, in housing policies.

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APPENDIX

TABLE I. SUMMARY OF DEPENDENT AND INDEPENDENT VARIABLES

	Variables	Definition	Categories/ Mean	%
Socioeconomic	General health	1 if poor, 0 if otherwise*	0	82.67
			1	17.33
	Gender	1 if male*, 0 if otherwise	0	54.50
			1	45.50
	Age	between 17 and 80	52.63	-
	Education level	Pre-primary*; primary; post primary	pre-primary	10.08
			primary	37.77
			post primary	52.16
	Marital status	single*; married; widowed; divorced	single	23.22
			married	58.16
			widowed	10.72
			divorced	7.91
	Economic status	employed ¹ * ² ; unemployed; retired; student; disabled; domestic	employed ¹	45.56
			employed ²	3.06
			unemployed	8.63
retired			29.97	
student			5.06	
disabled			2.75	
Income quintile	between 1* and 5	1	17.23	
		2	20.67	
		3	21.48	
		4	20.97	
		5	19.64	
Household size ^a	between 1 and 24	5.60	-	
Living conditions	House type	House ^a ³ ⁴ ; flat ⁵ ⁶	detached ³	39.52
			semi-detached ⁴	22.95
			≤ 10 dwellings ⁵	22.67
			≥ 10 dwellings ⁶	14.86
	Tenure status	Owner*; rental; other	owner	77.78
			rental	14.92
			other	7.30
	Damp & rot	1* if yes, 0 if otherwise	0	71.20
			1	28.80
	Ability to keep warm	1* if yes, 0 if otherwise	0	24.34
			1	75.66
Utility bills	1* if yes, 0 if otherwise	0	92.91	
		1	7.09	
Lack of daylight	1* if yes, 0 if otherwise	0	89.69	
		1	10.31	
Urbanization level	1* if urban, 0 if otherwise	0	35.23	
		1	64.77	
n=1600 T=4 nT=6400 *- reference category ^a equalized; ¹ full-time; ² part-time; ³ detached; ⁴ semi-detached ⁵ ≤ 10 dwellings ⁶ ≥ 10 dwellings				