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Adaptation to climate change: Air-conditioning and the role of remittances☆,☆☆

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ABSTRACT

Do remittances improve the ability of households to adapt to global warming? We try to answer this question by studying the behaviours of households in Mexico, a country that experiences a large and stable flow of remittances. Using an instrumental variable approach, we find an important role of remittances in the climate adaptation process. Remittances are used for adopting air-conditioning, which is an important cooling device for responding to high temperatures and to maintain thermal comfort at home. We exploit climate and income heterogeneity by showing that large differences exist in the use of remittances for climate adaptation between coastal and inland regions, as well as among different income groups. We conclude by quantifying the overall increase in welfare that households attain by adopting air-conditioning.

1. Introduction

Air-conditioning is increasingly penetrating countries worldwide (IEA, 2018) and upward trends are especially observed in the emerging economies of the tropics and subtropics. A growing literature has highlighted the relative importance of income in relation to climatic conditions (Sailor and Pavlova, 2003; McNeil and Letschert, 2010; Auffhammer and Mansur, 2014; De Cian et al., 2019; Randazzo et al., 2020), especially in the developing countries (Akpinar-Ferrand and Singh, 2010; Davis and Gertler, 2015; DePaula and Mendelsohn, 2010), and the fact that more households are about to reach an affluence level that makes air conditioners affordable. Prolonged exposure to extreme heat not only leads to thermal discomfort and reductions in working (Zander et al., 2015) and scholastic performance (Park et al., 2020), but can also cause dizziness, cramps, and cardiovascular and respiratory diseases (Basu and Samet, 2002; Barreca et al., 2016; Burgess et al., 2017). If heat stress affects the ability to accumulate human capital, in the long-term it can exacerbate existing inequalities. Access to air-conditioning is highly uneven, and current adoption rates are

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☆☆ The authors declare they have no financial or personal relationships with any person or organization that could inappropriately influence or bias in any way the following manuscript.
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lower in the countries that need it the most because more frequently exposed to high temperatures (Mastrucci et al., 2019). Within countries, adoption is highly concentrated among high-income deciles, leaving low-income households greatly exposed (Davis et al., 2021; Pavanello et al., 2021).

In the climate change literature, the process of adjustment to actual or expected changes in climate conditions is called *adaptation* (Smit and Wandel, 2006). Adaptive capacity refers to the ability to modify behaviours in order to better cope with existing or anticipated external stresses (Adger, 2006). Operating air-conditioning is a form of private or individual adaptation to climate change. Socio-economic conditions determine a household's adaptive capacity, which involves purchasing power and access to technology. The literature on adaptive capacity is highly fragmented (Siders, 2019), with heterogeneous contributions from diverse and disconnected disciplines. Still, scientific contributions from different fields of study agree on the importance of certain recurring determinants of adaptive capacity, namely education, technology, knowledge, and physical and financial resources. Financial assets have long been recognized as a crucial determinant of adaptive capacity (Smit and Wandel, 2006), and financial constraints are one of the barriers that can drive a wedge between desirable adaptation options and those that are actually implemented (Chambwera et al., 2015). Existing work on the drivers of adaptive capacity mainly focuses on the role of labour-related income and wealth (Yohe and Tol, 2002; Siders, 2019), while the potential contribution of non-labour-related income, such as remittances, remains inadequately studied.

Remittances are an important additional source of income that enables recipient households to invest also in riskier assets and activities. Officially recorded remittance flows to low- and middle-income countries reached $540 billion in 2020 (World Bank, 2021). Even during the COVID-19 pandemic, remittances remained stable, registering in 2020 a very limited decline of just 1.6% below 2019 levels (World Bank, 2021). Remittances have received much less attention compared to the direct migration or displacement of people caused by climate change (Gray and Mueller, 2012; Belasen and Polachek, 2013; Mastrorillo et al., 2016; Baez et al., 2017; Bosetti et al., 2018; Cattaneo and Peri, 2016). Independently of why people migrate, remittances can serve as an economic safety net for recipient households that remain in the sending countries (Yang and Choi, 2007; Defiesta et al., 2014) and, especially in poor and emerging countries with stark inequalities, remittances are an important financial resource for improving the adaptive capacity of recipient households unable to relocate (Gemenne and Blocher, 2017; Giannelli and Canessa, 2022). Remittances are not only a source of income, but they also enable social transactions that create new social values (Rahman and Fee, 2012). Migrants sending remittances can also transfer back to the sending country of origin new skills, knowledge, ideas, and social practices acquired in the destination regions. Remitters might control how their transfers are spent by modifying intra-household bargaining power in expenditure allocation. Through these intangible mechanisms, remittances can contribute to re-orientating expenditure decisions (Anghel et al., 2015; Levitt, 1998).

Within the economic literature of migration, several studies show that remittance income has a positive effect on the acquisition of durable goods (Airola, 2007; Adams and Cuecuecha, 2010a), but little attention has been given to what kind of durable goods are mostly affected. A few isolated contributions more closely related to our research have examined the relationship between remittances and energy consumption (Rahman et al., 2021; Akçay and Demirtaş, 2015), implicitly highlighting the role of more affordable energy-intensive appliances. Remittances are generally spent on consumption (Chami et al., 2005; Adams and Cuecuecha, 2010b; Clément, 2011), but also on productive goods and activities with positive effects on economic development. Remittances contribute to children's education (Cox-Edwards and Ureta, 2003; Kifle, 2007; Yang, 2008; Adams and Cuecuecha, 2010a; Mansour et al., 2011; Randazzo and Piracha, 2019), housing (Adams and Cuecuecha, 2010a), health (Taylor and Mora, 2006; Adams, 2011) and/or investments (Taylor and Mora, 2006; Woodruff and Zenteno, 2007; Mendola, 2008; Veljanoska, 2021). Income constraints limit a household's consumer preferences, and receiving remittances relaxes that constraint by expanding the range of budgetary allocations. According to the permanent income hypothesis, remittances represent a transitory source of income that is used differently from the more stable labour income. The latter, such as expected income, is more likely to be saved, while less predictable income streams – such as remittances – encourage asset accumulation. Several studies support the stronger effect of remittance income than other income sources on asset accumulation by households (e.g. Adams, 1998; Amuedo-Dorantes and Pozo, 2014).

Our paper builds upon the two streams of literature on climate adaptation and development economics, in order to investigate whether and how remittances on the acquisition of a specific type of durable good, namely air-conditioning, serves the purpose of adapting to rising temperatures. A recent paper by Veljanoska (2021), closely related to our work, looks at whether remittances promote fertilizer use among Uganda farmers as a means of coping with rainfall variability. The paper sees remittances as a source of financing new investments, and within the climate adaptation literature this is a way to improve adaptive capacity.

We focus our analysis on the impact of remittances on climate adaptation in Mexico, an emerging economy that is experiencing a rapid increase in the adoption of air-conditioning, in the context of a long tradition in remittance inflows. Because of its heterogeneous climate, Mexico is an ideal subject for an empirical study of air-conditioning. The country is 2,000+ miles long and its climate zones range from hot and humid tropics to arid deserts and high-altitude plateaus. Most of Mexico's remittances are sent by the millions of Mexicans living in the United States, where the household penetration rate of air-conditioning is above 85%.[1]

We use the Encuesta Nacional de Ingresos *y* Gastos de los Hogares (ENIGH), a nationally representative household income and expenditure survey that the Mexican Statistical Institute has carried out biennially since 1984. We rely on household data from 2008 to 2018. Our empirical strategy is based on an instrumental variable approach for dealing with the potential endogeneity

1 https://www.enerdata.net/publications/executive-briefing/the-future-air-conditioning-global-demand.html

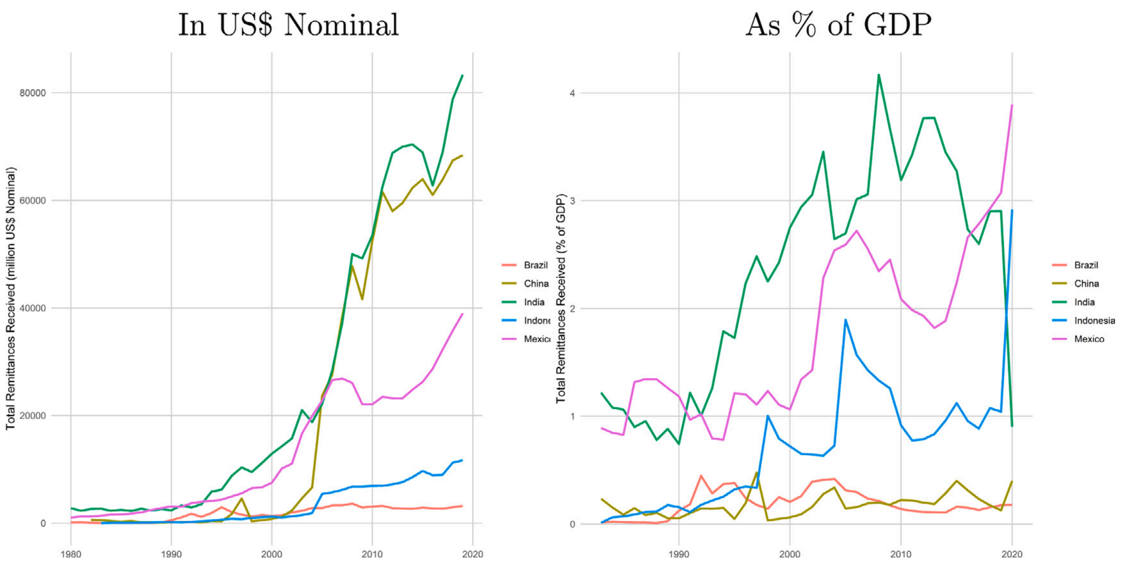

Fig. 1. Remittance inflows in five main emerging economies.

of remittance income. In line with previous studies, we find that climate and income are among the main drivers of the adoption of air-conditioning. Moreover, our variable of interest, remittance income, plays an additional role in the adaptation process. The probability of adopting air-conditioning increases by 8 percentage points when remittance income increases by 1000 pesos.[2] We exploit climate and income heterogeneity across Mexican households and states in order to show that remittances increase the ability of households to purchase air-conditioning (i) mostly in the coastal areas and (ii) especially when they have a relatively low-income level. We then underscore the potential private benefits of this form of adaptation by computing the 2018 consumer surplus gain associated with the possession of air-conditioning. The possession of air-conditioning increases the consumer surplus by between $231 and $988 million (2012 PPP), depending on the estimation model and method employed.

The remaining part of the paper is structured as follows. Section 2 provides some background on remittances and air-conditioning penetration in Mexico. Section 3 presents the descriptive statistics, while Section 4 describes our theoretical and empirical approach. Results are discussed in Sections 5 and 6, and the concluding remarks in Section 7.

2. Study context

Mexico is the third country in the world and the first in Latin America and the Caribbean region for inflows of international remittances, which reached 43 billion USD in 2020 (World Bank, 2021). The vast majority of these remittances are generated in the US, where almost 11 million Mexican nationals live.[3] Since the 1980s, the total value of remittances has steadily increased (Fig. 1), and in Mexico, more than in other emerging countries, remittances have significantly contributed to the country's economic development, accounting for 4% of its Gross Domestic Product (GDP) in 2020.

Mexico's steady inflow of remittances has attracted the attention of researchers and policy makers, who have analysed its implications for Mexican households and economy. Several studies on how recipient households perceive and use remittances in Mexico have found that migration and remittances reshape expenditure in favour of investments (Taylor and Mora, 2006; Chiodi et al., 2012; Woodruff and Zenteno, 2007). In Mexico, remittances affect schooling (Alcaraz et al., 2012; McKenzie and Rapoport, 2011; Borraz, 2005; Hanson and Woodruff, 2003), health (Hildebrandt et al., 2005), poverty, and labour supply (Amuedo-Dorantes and Pozo, 2006) and Amuedo-Dorantes and Pozo (2011b) show that remittances can also help to contrast income volatility. The empirical work on remittances conducted in Mexico provides evidence of how remittances promote growth and development. The role of remittances in the adaptation process has been neglected and we attempt to fill this gap in the literature by showing how remittances in Mexico can promote climate adaptation through the adoption of air-conditioning.

Over the last ten years, air-conditioning penetration rates have doubled (Davis and Gertler, 2015), but not all households are equally able to afford this form of investment for adaptation and, in 2018, only around 18% of Mexican households had at least one air conditioner installed in their dwellings.[4] Mexico's highly heterogeneous climate determines an uneven distribution between inland and coastal areas (Fig. 2). Temperatures are mild in the inland regions, where air-conditioning is relatively uncommon and adoption rates are close to zero. The coastal areas are exposed to much higher temperature levels, leading to higher penetration rates, reaching over 70% in some Pacific coastal states.

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[2] 1000 Mexican pesos correspond to 49 US$.

[3] https://www.migrationpolicy.org/article/mexican-immigrants-united-states-2019

[4] Authors' calculation based on ENIGH 2018.

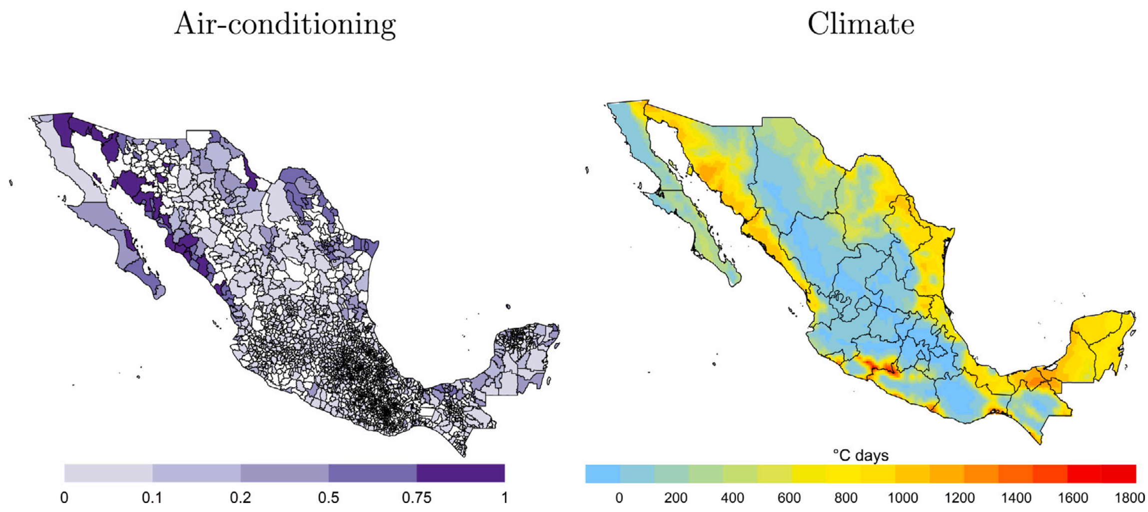

Fig. 2. Left: Share of households with Air-conditioning in 2018 (ENIGH); Right: Mean (1970–2018) CDD dry-bulb (GLDAS).

3. Data

The *Encuesta Nacional de Ingresos y Gastos de los Hogares* (ENIGH) is a nationally representative repeated cross-section survey carried out biannually by the Mexican statistical institute, INEGI. We use the last six available waves,[5] covering the 2008–2018 period and consisting of 229,236 sample households. The survey provides information on the size, origin and distribution of the income and expenditures of Mexican households. We focus our attention on international remittances, defined as monetary transfers that households have received from abroad during the previous three months.[6] The survey also contains a comprehensive module on housing and household appliances, which makes it possible to determine whether households have air-conditioners installed in their homes. However, we cannot differentiate between the various kinds of air-conditioning units (e.g. window, split, central), hence our results aim at capturing the impact of remittance income on the adoption of undifferentiated forms of air-conditioning.

We merge this data set with climate data taken from the reanalysis data set Global Land Data Assimilation System (GLDAS). Our climatic variable is the long-term annual average of dry-bulb Cooling Degree Days (CDDs), which measures typical intensity and duration of hot climate, and is widely used in the literature as determinants of space cooling (Davis and Gertler, 2015; De Cian et al., 2019; Pavanello et al., 2021). CDDs have been calculated by using daily temperature (°C) data computed from the 3-hourly global surface gridded temperature (0.25° × 0.25° resolution) fields obtained from the GLDAS (Rodell et al., 2004), from 1970 up to the corresponding wave year. For each grid-cell the CDDs are calculated by using the American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE) method (ASHRAE, 2009), and fixing 24 °C as temperature baseline. We use this threshold, rather than 18 °C, because Mexico is located between subtropical and tropical regions.

Descriptive statistics in Table 1[7] show that over the period 2008–2018 almost 6% of the households are remittance recipients, and they receive on average 7,459 pesos per quarter.[8] The air-conditioning adoption rate was around 17%, a figure that was significantly higher in non-recipient households (+6.8 percentage points). At the same time, households owning an air-conditioner received a significantly larger amount of international income remittance, showing that significant differences existed between households that owned an air-conditioner and those that did not (Table A.2). On average, remittance recipients received 12,782 pesos less in tri-monthly labour income than non-recipients and tended to be less educated. These two results suggest that recipient households, in order to overcome income constraints, are liable to resort to the strategy of migration and remittance. Our argument is also supported by the household head's employment status. Household heads in recipient families are less likely to be employed (61%), compared to non-recipient households (79%). We do not find significant differences in household size and presence of children based on household remittance status, whereas recipients are substantially more likely to have an elderly family member in the household (34%). The household head, on average, is older by five years in recipient households. As expected, recipient households also have a higher proportion of female heads compared to non-recipient households. Finally, remittance-recipient households are less concentrated in urban areas (45%) compared to non-recipients (68%), and they also experience lower temperatures – on average a difference of 85 CDDs between remittance-recipient and non-recipient households.

[5] Starting in 2008, INEGI has changed how it constructs income variables (*Nueva construcción*), making it difficult to consider previous waves

[6] In our analysis we focus only on international remittances. This is because for domestic remittances generated within Mexico, we do not have any information on where the remitter is located, and how internal migration is distributed inside Mexico. We follow (Amuedo-Dorantes and Pozo, 2006, 2011a,b), among others, who perform an empirical analysis based on international remittances only.

[7] In the Appendix we define each variable used in the empirical analysis (Table A.1).

[8] This corresponds to around 770$ per quarter.

Table 1
Descriptive Statistics for the period 2000–2018.

			Full Sample			
			Mean	SD		
Recipient (Yes = 1)			0.057	0.232		
Remittance Income (pesos) - if > 0			7,459.068	11,013.469		
Air-conditioning (Yes = 1)			0.166	0.372		
	Non Recipients		Recipients			
	Mean	SD	Mean	SD	Diff.	*p*-value
Air-conditioning (Yes = 1)	0.170	0.375	0.101	0.302	0.068	0.000
Long-term Mean CDD	383.879	419.002	298.274	392.776	85.604	0.000
Labour Income (pesos)	28,080.213	36,943.167	15,297.375	23,484.161	12,782.839	0.000
Total Income (pesos)	41,612.908	102,065.718	32,752.788	32,453.372	8,860.120	0.000
Urban (Yes = 1)	0.685	0.465	0.453	0.498	0.232	0.000
Female Head (Yes = 1)	0.252	0.434	0.425	0.494	−0.173	0.000
Head Age	48.830	15.775	53.710	17.269	−4.880	0.000
Head Education (None = 1)	0.257	0.437	0.447	0.497	−0.189	0.000
Head Education (Primary = 1)	0.212	0.409	0.222	0.416	−0.010	0.009
Head Education (Secondary = 1)	0.284	0.451	0.226	0.418	0.059	0.000
Head Education (Above = 1)	0.246	0.431	0.106	0.308	0.140	0.000
Child (< 15, Yes = 1)	0.549	0.498	0.549	0.498	−0.000	0.990
Elderly (> 65, Yes = 1)	0.213	0.409	0.343	0.475	−0.130	0.000
Home Ownership (Yes = 1)	0.717	0.450	0.747	0.435	−0.029	0.000
Head Employed (Yes = 1)	0.790	0.407	0.612	0.487	0.177	0.000
Household Size	3.733	1.885	3.730	2.069	0.003	0.819
Hist. Rem. 1992	0.176	0.100	0.228	0.114	−0.052	0.000
Avg. US Wage	25.409	2.118	25.587	2.115	−0.178	0.000
Hist. Rem. 1992 × Avg. US Wage	4.481	2.591	5.840	2.917	−1.359	0.000
Observations	216,158		13,078			

4. Empirical framework

4.1. Modelling demand for air-conditioning

We introduce a simple model for the demand for thermal comfort, following the framework used by Amuedo-Dorantes and Pozo (2011b) in the context of health care expenditure. We assume that each household i in a given location maximizes a utility function that depends on consumption of market good (X) and the availability of thermal comfort (T):

$$U_i = U(X_i, T_i) \tag{1}$$

Households may invest in thermal comfort (T) according to a production function that depends on the availability of air-conditioning (AC), the climatic conditions (C) in the given location d, and a set of households' characteristics ($\mathbf{H}$) such as demographics (e.g. age, household size), socio-economic conditions that include wealth and education, and unobservable factors (e.g. preferences).

$$T_i = f(AC_i, C_d, \mathbf{H}_i) \tag{2}$$

Assuming preferences do not change over time, each household maximizes its utility by reaching the highest indifference curve possible subject to a budget constraint. The budget constraint is a function of both non-labour income, which we identify in remittances (R), and labour income (I). Income from any source is used to pay for market good X (with price P_X) and for air-conditioning appliances (priced at P_{AC}). That is:

$$\max_{X,T} \quad U_i = U(X_i, T_i)$$
$$\text{s.t.} \quad P_X X_i + P_{AC} AC_i \leq R_i + I_i \tag{3}$$

The solution to this problem yields the optimal demand for air-conditioning:

$$AC = g(R, I, P_X, P_{AC}, C_d, \mathbf{H}_i) \tag{4}$$

An increase in remittances, all else being equal, produces an income effect that shifts a household's budget constraint to the right, enabling households to reach a higher indifference curve. Households with a higher disposable income can have access to a higher range of goods and consume more of the two normal goods, X and AC.

While both generic and remittance income are measured in monetary units, the literature provides ample evidence that a dollar (or peso) of remittance income is not the same as a dollar (peso) of wage income, because (i) remittance income is transitory as opposed to the permanent nature of wage income (Adams and Cuecuecha, 2010a) and (ii) the remitter has a bargaining power in orientating transfer allocation (Amuedo-Dorantes and Pozo, 2011b). While expected wage income is more likely to be saved (permanent income hypothesis), less predictable income streams such as remittances encourage asset accumulation (precautionary savings). Air-conditioning can be seen as a risky asset that in the long-term benefits health and human capital (e.g. protecting health). Hence, we expect remittance income to have a positive impact on the adoption of air-conditioning.

4.2. Empirical strategy

Starting from Eq. (4), we pool the six waves of data available over time to obtain our empirical model describing a household's adoption of air-conditioning:

$$AC_{i(t)} = \beta_0 + \beta_1 R_{i(t)} + \beta_2 CDD_{d(t)} + \mathbf{F}_{i(t)}\beta_3 + \mu_s + \delta_{(t)} + \epsilon_{i(t)} \tag{5}$$

where $AC_{i(t)}$ is a dummy variable taking value 1 if household i has an air-conditioner installed in its dwelling in year t, 0 otherwise. $R_{i(t)}$ indicates the tri-monthly international remittance income from migrants living abroad (in thousand pesos). Hence, our coefficient of interest β_1 is to be interpreted as the effect of an additional 1000 pesos of remittance income every three months on the likelihood of having an air-conditioner. The variable $CDD_{d(t)}$ is the long-term average of dry-bulb Cooling Degree Days (CDD) experienced in district d across the 1970-t period. We also include a vector $\mathbf{F}_{i(t)}$ which groups income I_i and a household's characteristics $\mathbf{H}_i$ from Eq. (4).[9] We check for unobservable time-unvarying effects on the state level, as well for time-varying common trends by the means of state- and year-fixed effects, μ_s and $\delta_{(t)}$, respectively, and capture the remaining unobserved factors with an error term $\epsilon_{i(t)}$.

It is however problematic to estimate Eq. (5) by using a Linear Probability Model (LPM) (Adams, 2011). Remittance income is likely to be endogenous for adopting air-conditioning, and so the disturbance term $\epsilon_{i(t)}$ is to be correlated with $R_{i(t)}$. In our study, households are likely to turn to remittance according to their socio-economic status (observable selection bias). Negative selection may imply that poor households receive more remittances, but at the same time they are less likely to invest in air-conditioning. This would induce a downward bias in the LPM estimates which we limit by checking for labour income and family size that are determinants of poverty status. In addition, because we exploit repeated cross-sectional data, we cannot net out unobservable household determinants of receiving remittance income that may also be correlated with the adoption of air-conditioning. Because of omitted variable bias, we again expect the LPM estimates to be downward biased. For instance, more risk adverse households might be less likely to send a family member abroad because successful migration itself (e.g. settling down and finding a good job) is uncertain. At the same time, risk-adverse households with limited resources are less likely to invest in new appliances since negative income shocks may always occur.

To address the endogeneity of remittance income, we exploit a two-stage least squares (2SLS) approach and model the remittance equation as follows:

$$R_{i(t)} = \gamma_0 + \gamma_1 HR_{u(s)} \times W_{s(t)} + \gamma_2 CDD_{d(t)} + \mathbf{F}_{i(t)}\gamma_3 + \mu_s + \delta_{(t)} + \upsilon_{i(t)} \tag{6}$$

here $R_{i(t)}$ is the remittance income of household i at time t. The component $HR_{us} \times W_{s(t)}$ is our instrumental variable, which is given by the interaction between the historical share of remittances in stratum u of state s[10] and the weighted average of the US hourly wage assigned to state s at time t, $W_{s(t)}$.[11] The error component $\upsilon_{i(t)}$ is assumed to be independent of the set of control variables. In order to identify the model, we need to include in the first stage equation variables that are correlated with the remittance income but are not directly affecting the adoption of air-conditioning. As presented above, the instrumental variable chosen is an interaction between: (i) a historical share of households receiving remittances in 1992, varying by state and stratum level; (ii) the annual average in hourly wage in US destination states weighted by Mexican share of migrants by state of residence, varying by state and year level. Using this interaction, rather than the two components separately, allows to introduce more variability,[12] which we can exploit to identify the effect of remittance income.

For the first component, we follow the studies using historical migration rates and migration networks as instruments for remittances (Woodruff and Zenteno, 2007; McKenzie and Rapoport, 2011; Acosta, 2011; Salas, 2014; Veljanoska, 2021). They have proven to be a good proxy for local remittance norms, namely places that are used to receiving remittances. Specifically, we use the share of households receiving remittances taken from the 1992 ENIGH wave. The ratio is that Mexican locations where households are historically more likely to be recipients also have better infrastructure for receiving remittances, and so at present receive a higher amount of remittance income. Here the assumption is that, once we check for all the other exogenous covariates, the historical share of households receiving remittances in 1992 does not affect the present-day adoption of air-conditioning, apart from the impact through current remittance transfers.

[9] We include in $\mathbf{F}$: labour income, a dummy for living in an urban area, a household head's education, a household head's employment status, a household head's gender and age, household size, home ownership, and dummy variables for the presence of elderly persons and minors in the household. Given that income tends to be particularly skewed in developing countries, as a robustness we run our empirical model adding a quadratic term of labour income. Results are qualitatively the same, and therefore we present the regression with linear labour income only.

[10] For each state we can identify four strata: urban, suburban, small village and rural. This means that in total the historical share of recipient households in 1992 has 128 different values, 4 for each of the 32 states.

[11] All time variation in our instrument comes from the variation in US wages, which vary over time (t). Instead, the historical share of remittances in stratum u of state s is collected just for the year 1992 and therefore the variation is only between state and stratus and is fixed over time.

[12] To build this instrument we refer to the shift-share literature — see e.g., Borusyak et al. (2022)

For the second component, we follow the approach of Amuedo-Dorantes and Pozo (2011a,b). We first compute an annual average hourly wage for each wave-year and US state.[13] Then, we gather public data from the Instituto de los Mexicanos en el Exterior (IME) to determine the migrants' preferred US destination states from each Mexican state.[14] Finally, we assign to each Mexican state a weighted US country average hourly wage based on these stock of emigrants.[15] The idea is that the wage level in US destinations for Mexican emigrants are correlated with their remittance outflows. Here, we assume that US labour market conditions over the years do not affect AC adoption in Mexico other than via their remittance inflows.

One possible concern related to our instrumental variable is a correlation between the historical share of recipient households and the current level of development in the Mexican states. We resolve this issue by including the state's fixed effects, μ_s, and we also double-check for state-level per capita GDP as well as for state-time linear trends. In the next sections we provide several tests for conducting a thorough inspection of the econometric validity of our instrument.

We estimate Eq. (6) by using an OLS estimator, even though we observe remittance income for only 6% of the sample. We do not exploit a Tobit model, since a non-linear first stage would lead to inconsistent results in the second stage (Angrist and Krueger, 2001). Moreover, assuming censoring of the dependent variable does not allow for the possibility of true zeros. For robustness, we combine both internal and international remittances to see whether our estimates remain unaffected. Finally, in both first- and second-stage regression, standard errors are clustered at a district-year level to correlate observations within the same municipality included in the survey wave.

5. Results

5.1. Impact of remittance income on air-conditioning adoption

Table 2 presents the summary of our main estimates of the impact of remittance income on the adoption of air-conditioning, whose full results are included in the Appendix (Table A.5). We first run an LPM as a baseline for the analysis (Columns (1)-(3), Table 2). When the endogeneity of remittances is not considered, we find that a thousand-peso increase in tri-monthly remittance income is associated with a rise in the probability of adopting air-conditioning by between −0.10 and 0.24 percentage points, depending on the specification. Yet, as discussed above, these estimates are likely to be downward biased.

Column (4) in Table 2 reports the second-stage estimates related to the impact of remittances on the adoption of air-conditioning when the potential endogeneity bias is addressed with a 2SLS IV model. Compared to the coefficient from the LPM estimates, we find a larger, significant effect. This is in line with the empirical literature on remittances showing that the remittance coefficient gets much larger when an IV-strategy is implemented.[16] In our case, a 1000-pesos rise in tri-monthly remittance income increases the probability of adopting air-conditioning by 8 percentage points.[17] This result suggests that remittances play a fundamental role in satisfying the cooling demand of Mexican households by relaxing credit constraints in accessing the technology. Our results also align with the existing evidence (Amuedo-Dorantes and Pozo, 2014) suggesting that the transitory nature of remittance income encourages asset accumulation. When that same specification is re-estimated by using fans (Table A.8), which are a much cheaper alternative to air-conditioning, remittance income reduces the purchase of this good. That is, recipient households tend to invest more in a "riskier" asset such as air-conditioning than in a less-risky asset such as fans. When we divide our sample into recipient and non-recipient households and re-estimate our main specification to include total income as the only income covariate,[18] we find that households that receive remittances are more likely to buy an air-conditioner. This result suggests that the two sub-samples have a different propensity to invest in air-conditioning (Table A.9).

The coefficients of the other covariates (Table A.5) are in line with recent studies that have explored the determinants of air-conditioning adoption in Mexico (Davis and Gertler, 2015; Pavanello et al., 2021). Climate conditions are also an important driver of the demand for air conditioners. A hundred-unit increase in CDDs raises the likelihood of adopting air-conditioning by 3 percentage points. We also find a positive effect of labour income on the adoption. A 1000-pesos rise in labour income increases the likelihood of adopting the technology by 0.11 percentage points, a much smaller marginal effect compared to the remittance income discussed above.[19,20] By keeping labour income and climate constant, several demographics, economic and technological characteristics remain

[13] https://www.bls.gov/

[14] http://www.ime.gob.mx/

[15] Take as an example the Mexican states of Sonora. 38.7% and 30.6% of the Mexican migrants from Sonora go to Arizona and California, respectively. This means that we assign to Sonora the annual US average hourly wage in Arizona and California, weighted with the share of migrants, 0.387 and 0.306, respectively.

[16] See for example Alcaraz et al. (2012), Amuedo-Dorantes and Pozo (2006), Cuadros-Meñaca (2020), Cuadros-Meñaca and Gaduh (2020), Quisumbing and McNiven (2010) and Veljanoska (2021).

[17] In other words, if we interpret our results in terms of elasticities, a 1% increase in remittance income leads to a 3.61 percentage points increase in air-conditioning adoption.

[18] Total income includes labour income, remittance income as well as other sources of income (such as capital income).

[19] We use labour income as opposed to total income because labour income excludes the income from physical and human capital assets, rents and interest. This distinction between labour income and capital income is important because capital income is generated by previous investment decisions in assets which remittances income may contribute to determine and this paper tries to explain (Adams, 1998). In the Appendix, Table A.5 allows for a direct comparison between linear remittance income and linear labour income showing a close to 73 fold difference between remittance and labour income effects. Our remittances-income ratio is in line with the literature (e.g. Veljanoska, 2021).

[20] The stronger effect of remittance income compared to labour income should be interpreted with caution. Alcaraz et al. (2012) state clearly that including income may cause some endogeneity problems. Additionally, from an econometric point of view, the effect of remittance income is a local average treatment effect (LATE) or complier average casual effect; the effect of income is an average treatment effect (ATE) which includes compliers and not compliers together.

Table 2
Impact of remittance income on air-conditioning adoption.

	LPM (1)	LPM (2)	LPM (3)	2SLS (4)
Remittance Income (in 1000s)	−0.0010**	0.0012***	0.0024***	0.0801**
	(0.0004)	(0.0002)	(0.0002)	(0.0337)
Mean CDD			0.0003***	0.0003***
			(3.97e−05)	(3.91e−05)
Covariates	No	No	Yes	Yes
State FE	No	Yes	Yes	Yes
Time FE	No	Yes	Yes	Yes
Effective F statistic				45.869
Montiel-Pflueger TSLS (τ = 5%)				37.418
Anderson-Rubin CI				[0.017, 0.153]
Observations	229,236	229,236	229,236	222,777

Notes: (1), (2), (3) and (4) clustered std. errors at district-year level in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Each equation includes as covariates: labour income, dummy for living in an urban area, household head's education, household head's employment status, household head's gender and age, household size, home ownership, and dummy variables for the presence of elderly persons and minors in the household. The table summarizes the estimation results presented in Table A.5 available in the Appendix.

important factors in explaining adoption patterns. Urbanization increases the likelihood of adopting the cooling durable (+9.3 percentage points) and so does home ownership. Education too substantially enhances the propensity to adopt the technology. Findings on gender suggest that the presence of a female family head decreases the propensity to adopt a cooling device (−4.7 percentage points).

Our first-stage results (Table A.4) indicate that the recipient households are negative selected, confirming what the descriptive statistics already suggested. For instance, both a household head's education and his/her employment have a negative impact on remittance income. Home ownership, which represents a measure of wealth, is negatively associated with remittances. In line with previous studies, we find that female-headed households are more likely to receive international remittances (+ 595 pesos) and that the presence of children in the household is another important determinant of remittances (+116 pesos) (e.g. Acosta, 2011; Amuedo-Dorantes and Pozo, 2011a). Our instrumental variable, given by the interaction between: (i) a historical share of households receiving remittances in 1992; (ii) the annual average in hourly wage in US destination states, is quite positively correlated with received remittances. This means that locations with greater remittance norms receive higher remittance income when there is an increase in the US hourly wage.

To verify the validity of our IV approach, we first implement Montiel Olea and Pflueger (2013), in which instruments are considered weak when the 2SLS bias is large relative to a benchmark. In our case, the effective F-statistic results are equal to 45.87, hence well above the Montiel-Pueger TSLS critical value at τ = 5%, with significance level set at 5%. We can therefore reject the null hypothesis of weak instrument and be confident that our estimates are unlikely to be biased by a weak instrument. To further inspect our instrument, we also report the 95% Anderson-Rubin confidence interval.[21] This confidence interval is robust to the presence of weak instruments and has the correct size under a variety of violations of the standard assumptions of the IV regression.

5.2. Heterogeneity: Coast and inland

Given Mexico's great climate heterogeneity, we explore whether remittances have a heterogeneous impact in warm and cold regions. We may indeed expect that only the recipient households living in high-temperature areas invest remittance income in air-conditioning purchase. We therefore divide our sample between households living in the warm coastal states and those living in the cold inland ones.[22] Table 3 shows the 2SLS estimates for these two subsamples. We find that remittance income is a significant driver of air-conditioning adoption in the coastal areas, whereas it has null effect in the inland areas. In terms of magnitude, in the coastal locations, remittances have an effect that is double in size compared to the estimates obtained when coastal and non-coastal locations are pooled together in the full sample specification. A 1000-pesos increase in tri-monthly remittance income increases the likelihood of adopting air-conditioning by 19 percentage points. As expected, recipient households tend to use the received remittances to increase their adaptive capacity, and adaptation opportunities only when they are exposed to high temperatures. Remittances are not only a source of income but can also have a social and cultural value that connect receiving to sending country communities and that can orientate expenditure decisions. Since most remittances are generated in the U.S., where air-conditioning is widely adopted, they might also have a contagious behavioural effect, especially in coastal areas where the temperatures are higher. In the inland regions, air-conditioning can be seen as a luxury good and not as a necessary need for a decent living, and

[21] We conduct the Anderson-Rubin test, and we can reject the null hypothesis of no effect of remittance income on air-conditioning adoption at 0.01 significance level. Results of the test are available upon request.

[22] Table A.3 presents descriptive statistics by area. Around 49% of the sample lives close to the coast (117,522 households) and 51% in inland areas (111,714 households). As expected, 24% of households living in the coastal areas possess air-conditioning while the percentage reduces to 8% in inland areas.

Table 3
Heterogeneous impact of remittance income on air-conditioning adoption: Inland vs coast.

	Inland (1)	Coast (2)
Remittance Income (in 1000s)	−0.0309	0.191**
	(0.0318)	(0.0764)
Mean CDD	0.0004***	0.0003***
	(3.31e−05)	(5.19e−05)
Covariates	Yes	Yes
State FE	Yes	Yes
Time FE	Yes	Yes
Effective F statistic	11.881	25.833
Montiel-Pflueger TSLS (τ = 5%)	37.418	37.418
Anderson-Rubin CI	[−0.125, 0.031]	[0.061, 0.381]
Observations	108,564	114,213

Notes: (1) and (2) clustered std. errors at district-year level in parentheses; *$p <$ 0.10, **$p < 0.05$, ***$p < 0.01$. Each equation includes as covariates: labour income, dummy for living in an urban area, household head's education, household head's employment status, household head's gender and age, household size, home ownership, and dummy variables for the presence of elderly persons and minors in the household. The table summarizes the estimation results presented in Table A.6 available in the Appendix.

therefore only the wealthy decide to adopt it, based on their income levels. In this case, remittances play no additional marginal role. However, the null effect of remittances for the inland households may not be precisely estimated. With a relatively weak instrument, the results for this subsample need to be interpreted with caution. Moreover, for the coastal sample we can reject the null hypothesis of a weak instrument only at 10% significance level, as we impose the Montiel-Pueger TSLS critical value at $\tau = 5\%$.[23] This suggests there might be some bias in these subsample estimates.[24]

5.3. Heterogeneity: Income groups

Due to asymmetries in access to financial markets, remittances might be more important for lower-income households facing tighter budget constraints than for higher-income households. We therefore study whether poorer households are more likely than richer households to spend remittance income on their cooling needs. We divide the sample into three groups, based on income terciles, and we re-estimate our model for low-, medium- and high-income households. Table 4 presents the 2SLS estimates for the three subgroups. We find households are less responsive to increases in remittance income as household income increases. For low-income households a 1000-pesos increase in tri-monthly remittance income makes it more likely to adopt air-conditioning by 6.8 percentage points. The effect is smaller for medium-income households, 4.6 percentage points, whereas it becomes non-significantly different from zero to high-income households.[25] Interestingly, labour income is not significant in the low and middle-income subsample. This suggests that poorer households can adopt the technology only if they receive resources in addition to labour income. Indeed, for poor households, labour income is primarily geared towards primary goods. Remittances, as an additional income source, can be invested in assets such as air-conditioning only after basic needs are fulfilled. These results are in line with Gertler et al. (2016), demonstrating that households faced with credit constraints become much more likely to purchase energy-using assets with additional income once their income passes a threshold level. In their paper they study the role of an unconditional cash programme, which, like remittance income, can be seen as transitory. In our context, remittance income may make it possible to surpass that threshold by increasing the adoption of air-conditioning. The situation is different for medium-income families, who can invest part of their labour income, together with remittances, in air-conditioning. Table 4 shows that the impact of remittances on air-conditioning is lower in comparison to poor households. Finally, high-income households do not need remittances to purchase air-conditioning, and we do not find any significant effect of remittances on its purchase. Our findings point at the importance of analysing the impact of remittances on cooling needs by income levels. We shed light on different perceptions that households in different income groups might have of air-conditioning. It might represent a normal good for high-income households and a luxury good for low-income households. We conclude that remittance income contributes to equalizing household adoption of air-conditioning by financing the purchase.

[23] The effective F statistic is slightly lower than the Montiel-Pueger TSLS critical value at $\tau = 5\%$, with significance level set at 5% (Table 3 and Table A.6). With $\tau = 10\%$, the same critical value is 25.8, and so it is smaller than our effective F statistic.

[24] The difference in instrument performance for the two sub-samples might be related to significant differences in the instrument mean and standard deviation across the two sub-samples (Table A.3).

[25] For the high-income sub-sample the first-stage regression F-test may suggest a weaker instrument. This might be due to the fact that richer households are less likely to receive remittances. For the high-income households labour income drives the adoption of air-conditioning (see Table A.7).

Table 4
Heterogeneous impact of remittance income on air-conditioning adoption: Income groups.

	Low-Income (1)	Med-Income (2)	High-Income (3)
Remittance Income (in 1000s)	0.0681**	0.0467*	0.0569
	(0.0290)	(0.0271)	(0.0398)
Mean CDD	0.000136***	0.000343***	0.000516***
	(0.0000220)	(0.0000457)	(0.0000483)
Covariates	Yes	Yes	Yes
State FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Effective F statistic	67.22	60.68	12.40
Montiel-Pflueger TSLS (τ = 5%)	37.42	37.42	37.42
Anderson-Rubin CI	[0.014, 0.129]	[−0.004, 0.106]	[−0.020, 0.169]
Observations	74,625	74,090	74,062

Notes: (1), (2) and (3) clustered std. errors at district-year level in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Each equation includes as covariates: labour income, dummy for living in an urban area, household head's education, household head's employment status, household head's gender and age, household size, home ownership, and dummy variables for the presence of elderly persons and minors in the household. The table summarizes the estimation results presented in Table A.7 available in the Appendix. Income groups are based on total income.

5.4. Robustness checks

We perform some robustness checks for our analysis. In Column (1), Table 5, we report our 2SLS estimates when we include the state-level per capita GDP. The estimates remain close to those obtained with the main specification, suggesting that state fixed effects are sufficient to check for the correlation between the historical share of recipient households and the current level of development in the Mexican states.

In Mexico City about 1% of households have air-conditioning, but here recipient households receive the highest amount of remittance income. We check whether excluding the capital may affect our estimates. In Column (2) we report the results, which remain robust.

In Column (3) we re-estimate our econometric model, including multiple instruments. Particularly, we use the interaction together with the two components alone. The objective is twofold: (i) to provide an over-identification test to examine the instruments' exogeneity; and (ii) to examine whether introducing a plurality of instruments may affect the magnitude of the effect of remittance income. We find a similar effect of remittance on the adoption of air-conditioning. Moreover, results for the Hansen J test allows us not to reject the hypothesis of exogeneity of our instruments. However, adding a plurality of instruments reduces the variability we can exploit to identify the effect of remittance income. Consequently, the first-stage regression F-test is much lower than before — but it remains above the commonly used threshold of 10.

One further concern for our analysis is that only 6% of our sample receives international remittances, and the large number of zeros might affect our estimates. For this reason, we create an alternative measure of remittance income, which combines remittances from both internal and international migrants. As a result, around 20% of households are now recipients. Column (4) reports the estimate by using the new definition of remittance. The results remain similar to our baseline estimate. Nevertheless, not unexpectedly, we note that our instrumental variables work better when applied only to international remittances.[26] Finally, in Column (5) we add state-time linear trends to check state-specific business cycles – also related to US employment conditions – that may influence both the penetration of air-conditioning and the amount of remittance income that Mexican households receive from abroad. The positive impact of remittance income is robust to this addition.

6. Quantifying the welfare gain from air-conditioning adoption

We have shown that providing Mexican households with additional non-labour income can relax credit constraints, making air conditioners more affordable. Air-conditioning has been shown to bring benefits in terms of reduced heat-related mortality (Barreca et al., 2016), and increased productivity and learning (Zivin and Kahn, 2016; Park et al., 2020). To quantify these gains in welfare, we estimate the full consumer surplus of Mexican households that owned an air-conditioner in 2018. In doing so, we closely follow Barreca et al. (2016), who compute the same measurement that is applied to the US. We specify the following conditional electricity demand function:

$$Q_i = \beta_0 + \beta_1 AC_i + \beta_2 P_s + \beta_3 AC_i \times P_s + \beta_4 CDD_d + \mathbf{Z}_i \beta_5 + \mu_s + \epsilon_i \tag{7}$$

[26] In some specifications, based on correlation and not on causation, we differentiate international remittance from internal remittance income. We find that both types of remittances have a positive and similar impact, in terms of magnitude, on the adoption of air-conditioning. However, without solving for internal remittance endogeneity, we cannot really compare the coefficients. Results available upon request.

Table 5
Robustness checks.

	Per Capita GDP (1)	No Mexico City (2)	More Instruments (3)	Total Remittances (4)	Linear Trend (5)
Remittance Income (in 1000s)	0.0795**	0.0817**	0.0780***	0.0855**	0.0823**
	(0.0337)	(0.0339)	(0.0301)	(0.0336)	(0.0344)
Mean CDD	0.0003***	0.0003***	0.0003***	0.0003***	0.0003***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Covariates	Yes	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Linear State-trend	No	No	No	No	Yes
Kleibergen-Papp rk Wald F statistic	45.872	45.371	17.970	28.833	45.198
Montiel-Pflueger TSLS (τ = 5%)	37.418	37.418	22.085	37.418	37.418
Anderson-Rubin CI	[0.0167, 0.153]	[0.019, 0.156]	[0.003, 0.177]	[0.020, 0.161]	[0.018, 0.157]
Lagrange multiplier K test			7.881		
Lagrange multiplier K test (p-value)			0.005		
K test CI			[0.024, 0.143]		
Hansen J			0.103		
Hansen J (p-value)			0.950		
Observations	222,777	213,466	222,777	222,777	222,777

Notes: (1), (2), (3), (4) and (5) clustered std. errors at district-year level in parentheses; $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. Each equation includes as covariates: labour income, dummy for living in an urban area, household head's education, household head's employment status, household head's gender and age, household size, home ownership, and dummy variables for the presence of elderly persons and minors in the household.

Table 6
Regression of electricity quantity on air-conditioning adoption — surplus gain computation in 2018.

	OLS (1)	OLS (2)	OLS (3)	DMcF (4)
Panel A: Electricity Demand				
Air-conditioning	1.564***	5.028***	4.115***	3.048***
	(0.149)	(0.598)	(0.376)	(0.340)
Electricity Price	−0.860***	−0.523***	−0.893***	−1.067***
	(0.078)	(0.024)	(0.169)	(0.163)
Elec. Price × AC		−1.226***	−1.023***	−0.592***
		(0.200)	(0.119)	(0.127)
Covariates	No	No	Yes	Yes
State FE	No	No	Yes	Yes
Selection Corr.	No	No	No	Yes
Observations	65,832	65,832	65,832	65,832
Panel B: Consumer Surplus Gain (in Billions $2012 PPP)				
No CO_2 Externality	0.928***	0.594***	0.334***	0.988***
	(0.102)	(0.062)	(0.058)	(0.241)
SCC = 6.85 $/t$CO_2$	0.849***	0.542***	0.295***	0.932***
	(0.099)	(0.057)	(0.056)	(0.235)
SCC = 18.16 $/t$CO_2$	0.719***	0.457***	0.231***	0.839***
	(0.097)	(0.050)	(0.052)	(0.226)
SCC = 69.11 $/t$CO_2$	0.133	0.074	−0.059	0.422***
	(0.104)	(0.057)	(0.044)	(0.187)

Notes: (1), (2), (3) and (4) clustered std. errors at district-year level in parentheses; $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. Eqs. (3) and (4) include as covariates: quintiles for total income, CDDs, and household size, quartiles for household head's age, dummy for living in an urban area, household head's education, household head's employment status, household head's gender, home ownership, and dummy variables for the presence of elderly persons and minors in the household. SCC values for Mexico are taken from Ricke et al. (2018). The number of households in Mexico in 2018 is about 35 million. Consumer surplus gain SEs are computed using the Delta Method.

where Q_i is the annual electricity demand (in 1000s kWh) of household i living in state s. AC_i indicates whether the household i as an air-conditioning system installed in its dwelling. P_s is the unit price of electricity in state s. The interaction $AC_i \times P_i$ allows air-conditioning to affect the slope of the electricity demand. $\mathbf{Z}_i$ vector containing household characteristics, including total income, and CDD indicates Cooling Degree Days.[27] Finally, μ_s represents state fixed-effects and ϵ_i is the error component. In this setting

[27] We include the same household characteristics used in the previous sections. However, for the sake of consistency with Barreca et al. (2016), in Table 6 we specify all household characteristics and Cooling Degree Days as dummies. Specifically, we create quintiles for CDD, total income and household size, and quartiles for household head age. We then conduct a robustness check by using both continuous and dichotomic covariates (Table A.11).

air-conditioning induces a shift in the electricity demand curve for adopters.[28] The surplus gain is then quantified by computing the area between the demand curves of adopters and non-adopters. Moreover, as opposed to Barreca et al. (2016), we also subtract the externality costs due to the CO2 emissions from air-conditioning use.[29] In doing so, we use three different median estimates[30] for the scenario RCP4.5-SSP2 of the Mexican Social Cost of Carbon (SCC) from Ricke et al. (2018). We estimate Eq. (7) by means of Dubin's and McFadden's (1984) discrete-continuous approach.[31] This allows us to simultaneously estimate both the intensive margin, i.e. the change in electricity use for a given level of air-conditioning stock, and the extensive margin, i.e. the change in electricity use due to an increase in the air-conditioning stock.

Table 6 shows our estimates for residential electricity demand. We find that air-conditioning raises residential electricity demand by 773–1564 kWh per year. Moreover, Columns (2)-(4) suggest that air-conditioning causes an even more precipitous rise in residential electricity demand. That is, air-conditioning makes electricity costs more sensitive to the increase in electricity quantity, indicating that households with air-conditioning are more sensitive to price changes.

Assuming a perfectly elastic supply of electricity, we then estimate that the gain in consumer surplus associated with the adoption of air-conditioning ranges from about $231 to $988 million (2012 PPP) at the 2018 air-conditioning penetration rate of 18% (Table 6). This translates into an increase in consumer surplus per household in 2018 of $7– $28 (2012 PPP). The per household gains in welfare double once we focus only on the coastal sample (Table A.10), where the increase is between 12$ and 50$ (2012 PPP) per household at the 2018 air-conditioning penetration rate (25%). Environmental costs reduce the welfare gains. In 2018, between 6% and 57% of the welfare gain from adopting air-conditioning is lost to due to the social costs of the additional CO2 emissions produced.

If we compare the case with no externality cost, the results are smaller than in Barreca et al. (2016), which find an increase by between $112 and $225 (2012 PPP) in consumer surplus per US household at the 1980 air-conditioning saturation rate (57%). This is likely due to country-specific characteristics. For instance, there might exist differences in the preferences for electricity consumption between Mexican and US households. Moreover, the large gap between the air-conditioning adoption rates likely influences the total surplus gain. While the computation provides an insightful approximate measurement of the expected private benefits associated with the adoption of air-conditioning in the specific context of Mexico, there are some important caveats. First, we have assumed a perfectly elastic supply, which is likely to be an oversimplification.[32] Second, we have no information on the capital cost of adopting the technology. Third, we do not take account of the possible endogeneity of electricity costs.[33]

The penetration of air-conditioning in Mexico is still low, and households owning this technology may be highly selective. The estimation of electricity demand may be sensitive to selection bias. Column (3) shows estimates with no selection correction, while Column (4) presents estimates based on the Dubin-McFadden approach, which through the selection term corrects the potential bias of electricity demand. This explains why the gain in welfare calculated on the basis of estimates in Column (3), which does not include the selection term, is much lower than the one calculated by using estimates provided by Column (4). The evidence we provide indicates that a certain bias exists.

7. Conclusion

Our paper contributes to understanding what role remittances can have in the climate adaptation process of households. By focusing on space cooling investments, we show that receiving remittance income strongly increases the likelihood of purchasing air-conditioning. This finding suggests that the availability of additional financial resources can indeed enhance the adaptive capacity of households, enabling them to adopt technologies that otherwise would not be affordable and that can contribute to reducing their vulnerability to climate change. For low-income households and for those exposed to a warm climate, remittance income can make a significant difference in their ability to adapt to climate change. For these households, remittances represent an additional financial resource that can be allocated for space cooling in the presence of income constraints. Moreover, we believe that remittances are not only a transitory source of income but that they also incorporate an additional social value. Mexican remittances originate prevalently from the United States, which is where the widespread use of air-conditioning was pioneered. From being a luxury system used originally in manufacturing to control indoor environmental quality, by 1980 it became a common feature in nearly all American households (Biddle, 2008). Migrant household members acquire new behaviours and social practices that can be transferred back to household members in their country of origin.

[28] See the area "abcd" highlighted in Fig. A.1 for the case of perfectly elastic supply.

[29] See the area "bcfe" in red in Fig. A.1 We compute the externality cost by: (1) Multiplying the marginal effect of air-conditioning on electricity demand by the average carbon intensity in Mexico – 0.21 kgCO2/kWh in 2018 (https://ourworldindata.org/co2/country/mexico); (2) Transforming CO2 from Kg to tons; (3) Multiplying the emissions by the Mexican SCCs and the total number of households in Mexico. We thank the reviewers for suggesting this extension.

[30] These are, respectively, the minimum, the median and the maximum value across all Ricke et al. (2018)'s median estimates for the RCP4.5-SSP2 scenario.

[31] Dubin and McFadden (1984) propose three methods to estimate discrete-continuous models. As in Barreca et al. (2016) we exploit the third alternative, which consists of correcting for the selection of air-conditioning adopters by including a selection term. The latter is constructed by using predicted probabilities from a logit regression with air-conditioning as a dependent variable. Similar to Barreca et al. (2016), in the first stage we include interactions between the dummies for household size and electricity price. These interactions are then dropped in the electricity equation to have identification.

[32] This would be a more plausible assumption if in Mexico electricity generation mainly came from renewables — which have zero marginal cost. However, according to the International Energy Agency, in 2019, fossil-fuel based power plants provided 73% of Mexico's electricity.

[33] We reduce the impact of this issue by exploiting average electricity costs rather than marginal electricity costs, gathering cost data from an external source: https://www.inegi.org.mx/app/preciospromedio/?bs=18

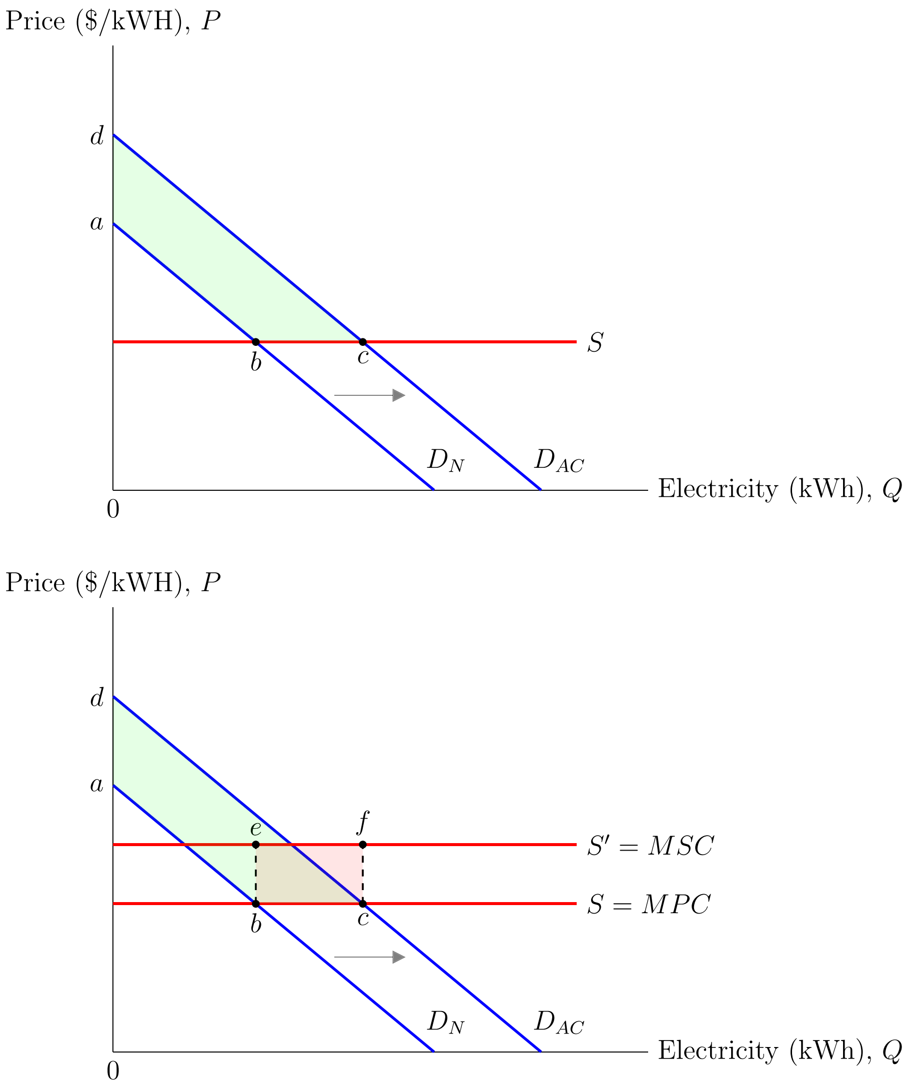

Fig. A.1. Above: Graphical representation of the Consumer Surplus Gain (abcd) with perfectly elastic supply S. D_N and D_{AC} are the demand of electricity from households without and with air-conditioning respectively. Below: Graphical representation of the Consumer Surplus Gain (abcd) with negative externalities (bcfe) from additional CO_2 emissions. MPC and MSC respectively represent the marginal private cost (supply S) and the marginal social cost (supply S').

We use a revealed preference approach based on the change in electricity expenditure induced by the availability of air-conditioning to determine a household's gains in welfare related to the purchase of this space cooling technology. We show that air-conditioning is an important means of adapting to climate change. In 2018, ownership of air conditioners generated an increase in consumer surplus of from $231 to $988 million (2012 PPP). These estimates should be taken with care. At the household level, they are expected to provide a lower boundary because the adoption of air-conditioning in Mexico is on an exponential growth trajectory. From a perspective of social well-being, we account for the negative externalities associated with air-conditioning. However, our estimates depend highly on the assigned social cost of carbon in Mexico, which is uncertain.

Warming temperatures will have harmful health impacts for exposed populations, particularly in emerging economies (Burgess et al., 2017), and air-conditioning has been shown to remarkably reduce mortality (Barreca et al., 2016). Yet, powering air-conditioning requires more electricity consumption, and this could contribute to creating new forms of vulnerability related to energy poverty. Socio-economic systems that depend on air-conditioning are more susceptible to collapsing under the impact of extreme weather events, such as heat waves, which will likely take place with ever-increasing frequency. Power outages that often occur during heat waves would then leave those households that depend on air-conditioning once again vulnerable.

Future research is needed for understanding whether there exist valid alternatives in a context such as Mexico, and what role remittances can play. Even when moving abroad, migrants remain in contact with their relatives living in their places of origin, and

Table A.1
List of variables.

	Type	Description
Recipient (Yes = 1)	Dummy	HH receives international remittances
Remittance Income (pesos)	Continuous	International remittance income
Air-conditioning (Yes = 1)	Dummy	HH has at least one AC
Mean CDD	Continuous	Long-term Average Cooling degree days
Labour Income (pesos)	Continuous	Labour income (wage)
Total Income (pesos)	Continuous	Total income
Urban (Yes = 1)	Dummy	HH lives in an urban area
Female Head (Yes = 1)	Dummy	HH head is female
Head Age	Continuous	HH head age
Head Education	Categorical	HH education level (4 categories)
Child (<15, Yes = 1)	Dummy	HH has at least one member below 15 yrs
Elderly (>65, Yes = 1)	Dummy	HH has at least one member above 65 yrs
Home Ownership (Yes = 1)	Dummy	HH owns its dwelling
Head Employed (Yes = 1)	Dummy	HH head is employed
Household Size	Ordinal	N° members
Hist. Rem. 1992 × Avg. US Wage	Continuous	Instrument

Table A.2
T-tests: Air-conditioning group.

	No AC	AC	Difference
Recipient (Yes = 1)	0.061	0.035	0.027***
Remittance Income (pesos)	7,094.243	10,700.584	−3,606.341***
Long-term Mean CDD	298.827	782.799	−483.972***
Labour Income (pesos)	24,512.561	41,647.830	−17,135.269***
Total Income (pesos)	36,113.754	66,260.482	−30,146.728***
Urban (Yes = 1)	0.639	0.834	−0.195***
Female Head (Yes = 1)	0.262	0.258	0.005*
Head Age	49.237	48.457	0.780***
Head Education (None = 1)	0.297	0.121	0.176***
Head Education (Primary = 1)	0.224	0.158	0.065***
Head Education (Secondary = 1)	0.279	0.292	−0.013***
Head Education (Above = 1)	0.200	0.429	−0.228***
Child (< 15, Yes = 1)	0.555	0.519	0.036***
Elderly (> 65, Yes = 1)	0.226	0.192	0.034***
Home Ownership (Yes = 1)	0.709	0.771	−0.062***
Head Employed (Yes = 1)	0.781	0.771	0.010***
Household Size	3.771	3.540	0.232***
Observations	191,264	37,972	

therefore they contribute to re-orientating expenditure and modifying the preferences of those remaining in the sending country by sharing new social norms or practices (Anghel et al., 2015). Whether the social value of remittances can support adaptive capacity through network effects and through changes in social preferences is difficult to quantify (Boccagni and Decimo, 2013), and this is left for future studies. A better understanding of the extent to which the social value of remittances can contribute to widespread adaptation practices can only be acquired by future research.

Appendix

Additional details on data, descriptives, and analysis

See Tables A.1–A.3 and Fig. A.1.

Additional results

See Tables A.4–A.11.

Table A.3
Descriptives: Coastal vs Inland areas.

	Inland		Coast		
	Mean	SD	Mean	SD	Difference
Recipient (Yes = 1)	0.062	0.242	0.051	0.220	0.009***
Remittance Income (pesos)	8,029.213	10,974.966	6,825.022	11,022.432	1,204.190***
Air-conditioning (Yes = 1)	0.087	0.281	0.241	0.428	−0.154***
Mean CDD	150.612	264.583	618.670	416.692	−462.901***
Labour Income (pesos)	28,398.917	37,160.588	26,354.769	35,694.454	2,044.148***
Total Income (pesos)	42,411.103	130,782.922	39,868.195	54,992.844	2,542.908***
Urban (Yes = 1)	0.680	0.466	0.663	0.473	0.017***
Female Head (Yes = 1)	0.258	0.438	0.265	0.441	−0.006**
Head Age	49.396	15.869	48.834	15.934	0.562***
Head Education (None = 1)	0.242	0.428	0.293	0.455	−0.051***
Head Education (Primary = 1)	0.221	0.415	0.205	0.404	0.016***
Head Education (Secondary = 1)	0.305	0.460	0.258	0.438	0.046***
Head Education (Above = 1)	0.232	0.422	0.244	0.429	−0.012***
Child (< 15, Yes = 1)	0.552	0.497	0.545	0.498	0.007***
Elderly (> 65, Yes = 1)	0.224	0.417	0.217	0.410	0.006***
Home Ownership (Yes = 1)	0.711	0.453	0.727	0.446	−0.015*
Head Employed (Yes = 1)	0.771	0.420	0.663	0.473	−0.016***
Household Size	3.776	1.901	3.692	1.890	0.083***
Hist. Rem. 1992	0.179	0.109	0.184	0.093	−0.011***
Avg. US Wage	25.011	1.944	25.807	2.202	−0.796***
Hist. Rem. 1992 × Avg. US Wage	4.334	2.769	4.774	2.470	−0.441***
Observations	111,714		117,522		

Notes: Mean and SD for Remittance Income are only for recipients HHs.

Table A.4
First stage estimation.

	OLS (1)
Hist. Rem. 1992 × Avg Wage US	0.0496***
	(0.00732)
Mean CDD	2.39e−05
	(4.34e−05)
Labour Income (in 1000s)	−0.0019***
	(0.0003)
Urban (Yes = 1)	−0.327***
	(0.0242)
Female Head (Yes = 1)	0.595***
	(0.0284)
Head Age	−0.0058***
	(0.0008)
Head Edu. (Primary = 1)	−0.0481**
	(0.0200)
Head Edu. (Secondary = 1)	0.00857
	(0.0212)
Head Edu. (Above = 1)	0.0215
	(0.0248)
Child (<15, Yes = 1)	0.116***
	(0.0206)
Elderly (>65, Yes = 1)	−0.0898***
	(0.0234)
Home Ownership (Yes = 1)	0.0344*
	(0.0187)
Head Employed (Yes = 1)	−0.656***
	(0.0341)
Household Size	0.0174***
	(0.0058)
State FE	Yes
Time FE	Yes
Observations	222,777
R-sq	0.031
F-test	45.869

Notes: Clustered std. errors at district-year level in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table A.5
Impact of remittance income on air-conditioning adoption.

	LPM (1)	LPM (2)	LPM (3)	2SLS (4)
Remittance Income (in 1000s)	−0.0010**	0.0012***	0.0024***	0.0801**
	(0.0004)	(0.0002)	(0.0002)	(0.0337)
Mean CDD			0.0003***	0.0003***
			(3.97e−05)	(3.91e−05)
Labour Income (in 1000s)			0.0010***	0.0011***
			(8.60e−05)	(0.0001)
Urban (Yes = 1)			0.0627***	0.0936***
			(0.0057)	(0.0146)
Female Head (Yes = 1)			−0.0010	−0.0470**
			(0.0016)	(0.0199)
Head Age			0.0008***	0.0013***
			(9.45e−05)	(0.0002)
Head Edu. (Primary = 1)			0.0375***	0.0406***
			(0.0024)	(0.0034)
Head Edu. (Secondary = 1)			0.0713***	0.0708***
			(0.0040)	(0.0043)
Head Edu. (Above = 1)			0.1630***	0.1610***
			(0.0080)	(0.0081)
Child (<15, Yes = 1)			0.0094***	0.0002
			(0.0020)	(0.0047)
Elderly (>65, Yes = 1)			−0.00297	0.00316
			(0.0024)	(0.0040)
Home Ownership (Yes = 1)			0.0421***	0.0397***
			(0.0028)	(0.0037)
Head Employed (Yes = 1)			−0.0142***	0.0371*
			(0.0024)	(0.0219)
Household Size			−0.0034***	−0.0048***
			(0.0007)	(0.0010)
State FE	No	Yes	Yes	Yes
Time FE	No	Yes	Yes	Yes
Effective F statistic				45.869
Montiel-Pflueger TSLS (τ = 5%)				37.418
Anderson-Rubin CI				[0.017, 0.153]
Observations	229,236	229,236	229,236	222,777

Notes: (1), (2), (3) and (4) clustered std. errors at district-year level in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table A.6
Heterogeneous impact of remittance income on air-conditioning adoption: Inland vs coast.

	Inland (1)	Coast (2)
Remittance Income (in 1000s)	−0.0309	0.191**
	(0.0318)	(0.0764)
Mean CDD	0.000406***	0.000279***
	(0.0000331)	(0.0000519)
Labour Income (in 1000s)	0.000559***	0.00162***
	(0.0000909)	(0.000274)
Urban (Yes = 1)	0.0441***	0.111***
	(0.0166)	(0.0210)
Female Head (Yes = 1)	0.0250	−0.0817**
	(0.0247)	(0.0323)
Head Age	−0.0000454	0.00193***
	(0.000296)	(0.000379)
Head Edu. (Primary = 1)	0.0202***	0.0587***
	(0.00302)	(0.00791)
Head Edu. (Secondary = 1)	0.0414***	0.0979***
	(0.00418)	(0.00811)
Head Edu. (Above = 1)	0.0943***	0.215***
	(0.00891)	(0.0133)
Child (<15, Yes = 1)	0.00653	−0.00705
	(0.00495)	(0.0102)
Elderly (>65, Yes = 1)	−0.00516	0.0150

(*continued on next page*)

Table A.6 (*continued*).

	Inland (1)	Coast (2)
	(0.00385)	(0.0101)
Home Ownership (Yes = 1)	0.0286***	0.0456***
	(0.00367)	(0.00690)
Head Employed (Yes = 1)	−0.0319	0.0867*
	(0.0241)	(0.0443)
Household Size	−0.000990	−0.00536***
	(0.00124)	(0.00189)
State FE	Yes	Yes
Time FE	Yes	Yes
Effective F statistic	11.881	25.833
Montiel-Pflueger TSLS (τ = 5%)	37.418	37.418
Anderson-Rubin CI	[−0.125, 0.031]	[0.061, 0.381]
Observations	108,564	114,213

Notes: (1) and (2) clustered std. errors at district-year level in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table A.7
Heterogeneous impact of remittance income on air-conditioning adoption: Income groups.

	Low-Income (1)	Med-Income (2)	High-Income (3)
Remittance Income (in 1000s)	0.0681**	0.0467*	0.0569
	(0.0290)	(0.0271)	(0.0398)
Mean CDD	0.000136***	0.000343***	0.000516***
	(0.0000220)	(0.0000457)	(0.0000483)
Labour Income (in 1000s)	0.00144	0.00223	0.000642***
	(0.00115)	(0.00177)	(0.000158)
Urban (Yes = 1)	0.0476***	0.0784***	0.116***
	(0.00715)	(0.0145)	(0.0383)
Female Head (Yes = 1)	−0.0124	−0.0264*	−0.0554
	(0.00795)	(0.0159)	(0.0338)
Head Age	0.000568***	0.00102***	0.00180***
	(0.000157)	(0.000387)	(0.000635)
Head Edu. (Primary = 1)	0.0195***	0.0400***	0.0694***
	(0.00251)	(0.00629)	(0.0173)
Head Edu. (Secondary = 1)	0.0324***	0.0657***	0.107***
	(0.00333)	(0.00794)	(0.0162)
Head Edu. (Above = 1)	0.0727***	0.121***	0.205***
	(0.00605)	(0.0106)	(0.0228)
Child (<15, Yes = 1)	−0.00642	0.00879*	0.00475
	(0.00404)	(0.00489)	(0.0108)
Elderly (>65, Yes = 1)	0.00684*	0.00695	0.00121
	(0.00391)	(0.00835)	(0.00644)
Home Ownership (Yes = 1)	0.0122***	0.0360***	0.0492***
	(0.00236)	(0.00353)	(0.00585)
Head Employed (Yes = 1)	0.0225***	0.0103	0.0182
	(0.00869)	(0.0117)	(0.0347)
Household Size	0.00224***	−0.00833***	−0.0120***
	(0.000657)	(0.000916)	(0.00163)
State FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Effective F statistic	67.224	60.685	12.401
Montiel-Pflueger TSLS (τ = 5%)	37.418	37.418	37.418
Anderson-Rubin CI	[0.014, 0.129]	[−0.004, 0.106]	[−0.020, 0.169]
Observations	74,625	74,090	74,062

Notes: (1), (2) and (3) clustered std. errors at district-year level in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Income groups are based on total income.

Table A.8
Impact of remittance income on fan adoption.

	LPM (1)	2SLS (2)
Remittance Income (in 1000s)	0.00292***	−0.0577**
	(0.0004)	(0.0249)
Mean CDD	0.0004***	0.0004***
	(0.0000)	(0.0000)
Covariates	Yes	Yes
State FE	Yes	Yes
Time FE	Yes	Yes
Kleibergen-Papp rk Wald F statistic		45.866
Montiel-Pflueger TSLS (τ = 5%)		37.418
Anderson-Rubin CI		[−0.112,−0.011]
Observations	229,234	222,775

Notes: (1) and (2) clustered std. errors at district-year level in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Each equation includes as covariates: labour income, dummy for living in an urban area, household head's education, household head's employment status, household head's gender and age, household size, home ownership, and dummy variables for the presence of elderly persons and minors in the household.

Table A.9
Impact of Total income on air-conditioning adoption of recipient and non-recipient households.

	Recipients (1)	Non-recipients (2)
Total Income (in 1000s)	0.00103***	0.000208*
	(0.0001)	(0.0001)
State FE	Yes	Yes
Time FE	Yes	Yes
Observations	13,078	216,158

Notes: (1) and (2) clustered std. errors at district-year level in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Coefficients are LPM estimations. Total income is the sum of labour income and remittance income. Each equation includes as covariates: dummy for living in an urban area, household head's education, household head's employment status, household head's gender and age, household size, home ownership, and dummy variables for the presence of elderly persons and minors in the household.

Table A.10
Regression of electricity quantity on air-conditioning adoption — surplus gain computation for coastal areas.

	OLS (1)	OLS (2)	OLS (3)	DMcF (4)
Panel A: Electricity Demand				
Air-conditioning	1.894***	4.563***	4.159***	2.691***
	(0.159)	(0.624)	(0.411)	(0.364)
Electricity Price	−1.015***	−0.640***	−0.790***	−1.047***
	(0.109)	(0.039)	(0.159)	(0.154)
Elec. Price × AC		−0.980***	−1.002***	−0.399***
		(0.220)	(0.135)	(0.127)
Covariates	No	No	Yes	Yes
State FE	No	No	Yes	Yes
Selection Corr.	No	No	No	Yes
Observations	32,720	32,720	32,720	32,720
Panel B: Consumer Surplus Gain (in Billions $2012 PPP)				
No CO_2 Externality	0.757***	0.548***	0.350***	0.621***
	(0.094)	(0.070)	(0.123)	(0.087)
SCC = 6.85 $/t$CO_2$	0.716***	0.513***	0.325***	0.589***
	(0.093)	(0.068)	(0.123)	(0.085)
SCC = 18.16 $/t$CO_2$	0.648***	0.454***	0.283**	0.535***

(*continued on next page*)

Table A.10 (*continued*).

	OLS (1)	OLS (2)	OLS (3)	DMcF (4)
	(0.091)	(0.065)	(0.122)	(0.083)
SCC = 69.11 $/tCO_2$	0.344***	0.190***	0.0942	0.294***
	(0.088)	(0.058)	(0.117)	(0.075)

Notes: (1), (2), (3) and (4) clustered std. errors at district-year level in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Eqs. (3) and (4) include as covariates: quintiles for total income, CDDs, and household size, quartiles for household head's age, dummy for living in an urban area, household head's education, household head's employment status, household head's gender, home ownership, and dummy variables for the presence of elderly persons and minors in the household. SCC values for Mexico are taken from Ricke et al. (2018). The number of households in the coastal states of Mexico in 2018 is about 15 million. Consumer surplus gain SEs are computed using Delta Method.

Table A.11
Regression of electricity quantity on air-conditioning adoption — surplus gain computation using continuous covariates.

	OLS (1)	OLS (2)	OLS (3)	DMcF (4)
Panel A: Electricity Demand				
Air-conditioning	1.564***	5.028***	4.256***	2.902***
	(0.149)	(0.598)	(0.377)	(0.327)
Electricity Price	−0.860***	−0.523***	−0.845***	−1.071***
	(0.078)	(0.024)	(0.163)	(0.159)
Elec. Price × AC		−1.226***	−1.099***	−0.553***
		(0.200)	(0.119)	(0.116)
Covariates	No	No	Yes	Yes
State FE	No	No	Yes	Yes
Selection Corr.	No	No	No	Yes
Observations	65,832	65,832	65,832	65,832
Panel B: Consumer Surplus Gain (in Billions $2012 PPP)				
No CO_2 Externality	0.928***	0.594***	0.309*	1.121***
	(0.102)	(0.062)	(0.181)	(0.173)
SCC = 6.85 $/tCO_2$	0.850***	0.543***	0.275	1.066***
	(0.099)	(0.057)	(0.180)	(0.168)
SCC = 18.16 $/tCO_2$	0.720***	0.458***	0.220	0.975***
	(0.097)	(0.050)	(0.178)	(0.161)
SCC = 69.11 $/tCO_2$	0.134	0.074	−0.029	0.565***
	(0.104)	(0.058)	(0.173)	(0.133)

Notes: (1), (2), (3) and (4) clustered std. errors at district-year level in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Eqs. (3) and (4) include as covariates: total income, CDDs, dummy for living in an urban area, household head's education, household head's employment status, household head's gender and age, household size, home ownership, and dummy variables for the presence of elderly persons and minors in the household. The Social Cost of Carbon (SCC) values for Mexico are taken from Ricke et al. (2018). The number of households in Mexico in 2018 is about 35 million. Consumer surplus gain SEs are computed using Delta Method.

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