Leveraging mobile phones to attain sustainable development

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For billions of people across the globe, mobile phones enable relatively cheap and effective communication, as well as access to information and vital services on health, education, society, and the economy. Drawing on context-specific evidence on the effects of the digital revolution, this study provides empirical support for the idea that mobile phones are a vehicle for sustainable development at the global scale. It does so by assembling a wealth of publicly available macro- and individual-level data, exploring a wide range of demographic and social development outcomes, and leveraging a combination of methodological approaches. Macro-level analyses covering 200+ countries reveal that mobile-phone access is associated with lower gender inequality, higher contraceptive uptake, and lower maternal and child mortality. Individual-level analyses of survey data from sub-Saharan Africa, linked with detailed geospatial information, further show that women who own a mobile phone are better informed about sexual and reproductive health services and empowered to make independent decisions. Payoffs are larger among the least-developed countries and among the most disadvantaged micro-level clusters. Overall, our findings suggest that boosting mobile-phone access and coverage and closing digital divides, particularly among women, can be powerful tools to attain empowerment-related sustainable development goals, in an ultimate effort to enhance population health and well-being and reduce poverty.

mobile phones | SDGs | gender equality

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The potential for information and communication technologies (ICTs) to empower marginalized communities and promote sustainable development goals (SDGs) has been recognized among scholars and policymakers (1–3). The digital revolution brought about by the diffusion of mobile phones has allowed several countries with otherwise poor infrastructure—such as countries in sub-Saharan Africa and South Asia—to leapfrog communication technologies such as phone landlines and fixed internet connections (e.g., broadband) (Fig. 1 and *SI Appendix*, Fig. S1), with immense social implications. Growing evidence from specific contexts has shown that mobile phones—small, relatively inexpensive, yet incredibly powerful devices—can facilitate effective communication and connectivity, as well as access to information and vital services linked to health, education, and the economy.

This study expands context-specific evidence about the role of mobile phones in affecting sustainable development to a global scale. We show that access to mobile phones is positively associated with multiple indicators linked to global social development, such as lower gender inequalities, enhanced contraceptive use, and lower maternal and child mortality. We do so by assembling a wealth of publicly available macro- and individual-level data[†]; exploring a wide range of demographic and social development outcomes tied to women's decision-making power, health, and well-being; and leveraging a combination of datasets and methodological approaches, some of which (individual-level) allow us to draw causal inferences.

Mobile phones serve a range of functions across low- and middle-income countries (LMICs). With the maturation of technology and expansion of mobile-data networks, the capabilities of mobile phones have significantly expanded from enabling communication to the provision of information and the delivery of services (4). Mobile-phone–based healthcare interventions have been extensively implemented to improve appointment compliance, treatment adherence, and connectivity to enhance the capacity of remote and lesser-trained health staff (5–7). Effects of these interventions have been documented on improved antenatal care attendance (8), reduced perinatal mortality (9), improved clinical outcomes of HIV-positive pregnant women (10), and increased contraceptive use (11, 12) and acceptability (13). The increased affordability of mobile phones has the potential to facilitate autonomy and empowerment-related

Significance

Although mobile phones have diffused rapidly even in remote parts of the world with otherwise poor infrastructure, digital divides persist. This study provides large-scale evidence that the expansion of mobile phones is associated with lower gender inequalities, higher contraceptive use, and lower maternal and child mortality, with bigger payoffs among the poorest countries. Micro-level analyses further show that the ownership of mobile phones has narrowed the information gap about reproductive and sexual health and empowered women to make independent decisions. Boosting mobile-phone access and coverage and overcoming digital divides within and among the poorest countries has immense implications for sustainable development. Findings from this study speak to scholars and policymakers interested in the effect of technology on sustainable development goals.

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Data deposition: The macro-level dataset and codes needed to link the micro-level data are deposited in the Open Science Framework data collection (https://osf.io/27ktq/). Our code will enable readers to replicate the main results of this paper.

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[†]See *SI Appendix*, Table S1.

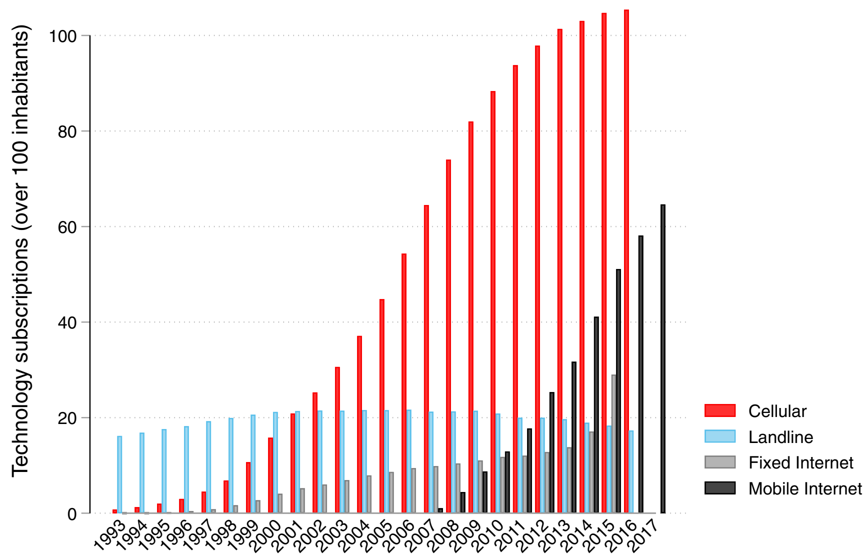

Fig. 1. ICT penetration worldwide from 1993 to 2017. ICT penetration by world region 1993 to 2017 is shown in *SI Appendix*, Fig. S1. Source: our elaboration from ITU data.

outcomes especially for women, through channels such as enhanced financial independence and better labor-market prospects (14), more decision-making power in domestic and public domains (15), and effectively releasing women's time in caring and domestic work (16). Studies also point to a link between mobile phones and increased food security and dietary quality (17) and better educational outcomes (18). Thus, if the potential of mobile phones is leveraged adequately, this technology promises to be a cost-efficient tool that fosters the realization of several key United Nations (UN) SDGs. Mobile phones can play a crucial role in ensuring healthy lives and promoting individual well-being at all ages (SDG 3—"good health and well-being"), and achieving gender equality by empowering girls and women (SDG 5—"gender equality"), as ways to ultimately reduce poverty in all its forms (SDG 1—"no poverty") and achieve key population targets (19, 20).[‡]

Women's empowerment and sexual and reproductive rights are essential building blocks in sustainable development strategies (21, 22). According to UN estimates, in 2017 just over 50% of women between 15 and 49 y of age who are married or in union are able to make their own decisions about consensual sexual relations and make use of contraceptives and health services (23). The lack of appropriate information and poor connectivity to health services are significant bottlenecks for the uptake of contraceptives (22, 24). The information and connectivity gap combined with a lack of decision-making power and autonomy has significant implications for the health and well-being of women, as well as that of their children (25). Improving access to information can play a crucial role in improving sexual and reproductive health, as informed women can make more conscious choices in terms of contraception, protection from sexually transmitted diseases, and antenatal care. Access to reproductive healthcare and information is, however, not easy in remote and poor areas around the world. Mobile phones can be instrumental in narrowing the information gap and in enabling service seeking to people in need. Higher-quality connectivity through mobile phones can also enable lesser-trained care providers to better support their target populations.

[‡] https://www.un.org/sustainabledevelopment/.

Previous research has documented the positive impact that media technology, such as TV, has had on promoting women's empowerment through exposure to new attitudes, knowledge, and behaviors (26, 27). Mobile phones offer enhanced capabilities, including the ability to access these benefits privately, which is essential in contexts where social norms are restrictive and might hamper women's access to information resources and ability to connect directly with healthcare providers (28). This potential is explicitly acknowledged within the SDG goal 5 (target 5B), which seeks to harness ICTs such as mobile phones as a pathway toward women's empowerment and well-being (29). Drawing on a range of social and demographic outcomes linked to gender inequality, reproductive and sexual health, and women's empowerment, in this study we provide both macro- and individual-level evidence that this is indeed one promising pathway.

Global Macro-level Evidence

Our macro-level analyses build on pooled data for 209 countries between 1993 and 2017 and seek to provide broad associational evidence between mobile-phone diffusion and global development indicators to further motivate micro-level investigations that follow. We combine country-level data from the International Telecommunication Union (ITU), the World Bank (WB), and the UN. Outcome measures include the gender inequality index (GII), the prevalence of modern contraceptive methods, the maternal mortality ratio, and under 5 y old child mortality. The GII is a comprehensive macro-level indicator of gender inequality comprising three subdimensions of human development—reproductive health, empowerment, and economic status—widely used by social scientists to measure gender dynamics and female empowerment (29–31), as well as by policymakers to track progress toward the attainment of the SDGs (32). *SI Appendix*, Table S2 provides a complete description of the outcome measures.

Fig. 2 provides global correlations between a measure of mobile-phone diffusion—defined as the ratio between the number of mobile-phone subscriptions and the total population—and sustainable development outcomes. Fig. 2, *Left* shows, for each country–year, the relationship between mobile-phone diffusion and the four outcomes, including the least-squares lines (in yellow). At the global level, mobile-phone diffusion is negatively

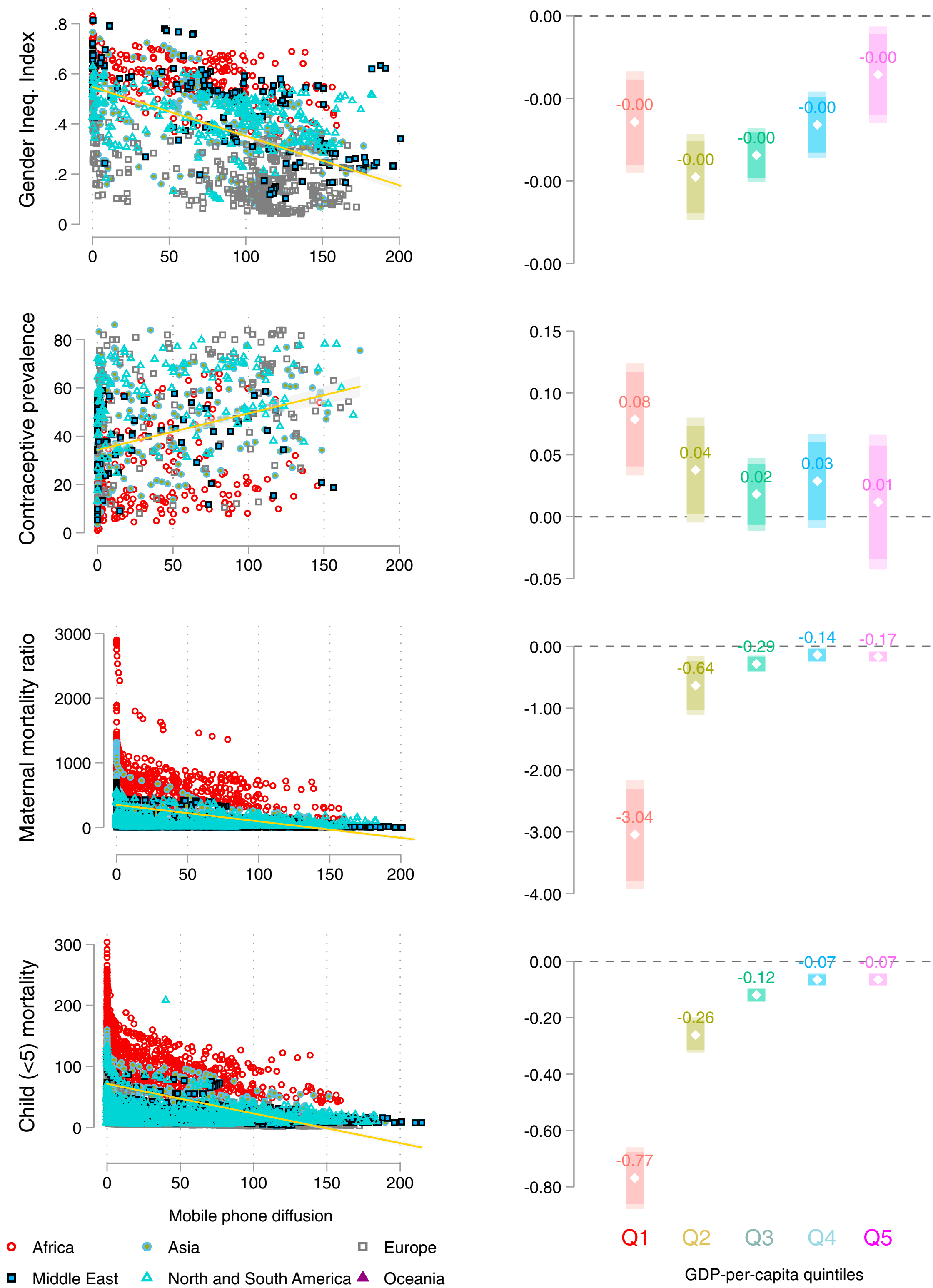

Fig. 2. Global correlations between mobile-phone diffusion and sustainable development outcomes. (*Left*) Correlations between mobile-phone diffusion and sustainable development outcomes by geographical areas. (*Right*) Standardized coefficients from univariate models regressing mobile-phone diffusion on sustainable development outcomes by GDP per-capita quintiles. The gray dashed line corresponds to zero, i.e., no association, while the darker and lighter bands surrounding the white circle correspond to the 95 and 90% confidence intervals, respectively. Source: our elaboration from ITU, World Bank, and UN data. Analyses are based on all available data for 209 countries from 1993 to 2017.

correlated with gender inequality as measured by the GII ($r = -0.51$; P value $= 0.000$), positively correlated with contraceptive prevalence ($r = 0.31$; $P = 0.000$), and negatively correlated with maternal ($r = -0.37$; $P = 0.000$) and child ($r = -0.47$; $P = 0.000$) mortality. These associations show nonlinearities across levels of economic development measured by gross domestic

Table 1. Associations between mobile-phone diffusion and sustainable development outcomes, by GDP per-capita quintiles

	1)	2)	3)	4)
	Gender inequality index	Contraceptive prevalence	Maternal mortality	Child mortality
Panel 1: Q1 to Q2				
Mobile phone subpopulation/population	−0.146* (0.073)	0.078** (0.036)	−0.184*** (0.063)	−0.300*** (0.066)
Education: lower sector, 25+ y old	0.170 (0.244)	0.207** (0.094)	−0.199 (0.218)	−0.152 (0.357)
GDP per capita	−1.682 (1.256)	−0.885 (0.660)	1.143 (0.927)	−0.624 (0.928)
Population density	−2.744 (3.610)	1.525* (0.801)	1.577 (1.275)	1.039 (1.996)
N	194	210	241	243
Within R^2	0.247	0.396	0.339	0.399
Panel 2: Q3 to Q5				
Mobile phone subpopulation/population	−0.099*** (0.020)	0.058* (0.035)	−0.016** (0.006)	−0.063*** (0.012)
Education: lower sector, 25+ y old	−0.286*** (0.071)	0.018 (0.098)	−0.003 (0.009)	−0.022 (0.019)
GDP per capita	−0.161** (0.078)	−0.225 (0.144)	−0.015 (0.010)	−0.041 (0.030)
Population density	−0.171* (0.091)	2.968 (2.178)	0.032** (0.015)	0.130*** (0.036)
N	852	516	911	902
Within R^2	0.559	0.089	0.160	0.447
Panel 3: Overall sample				
Mobile phone subpopulation/population	−0.102*** (0.020)	0.062* (0.033)	−0.014** (0.006)	−0.057*** (0.011)
Q1 to Q2	−0.008 (0.063)	−0.016 (0.072)	−0.066 (0.048)	0.022 (0.072)
Q1 to Q2 × mobile phone subpopulation/population	−0.021 (0.038)	0.023 (0.044)	−0.162*** (0.058)	−0.267*** (0.063)
Controls	✓	✓	✓	✓
N	1,046	726	1,152	1,145
Within R^2	0.499	0.153	0.297	0.453

Panel data fixed-effects models (standardized coefficients) are shown. SEs robust to heteroskedasticity are reported in parentheses. Control variables: educational attainment (lower secondary education, population 25+ y old), GDP per capita, and population density. Time span: 1993 to 2017. Data are linearly interpolated when missing. *$P < 0.10$, **$P < 0.05$, ***$P < 0.01$.

product (GDP) per-capita quintiles (Fig. 2, *Right*) and are on average higher in absolute values for the lowest quintiles. These GDP gradients take the form of J—or reversed-J—curves, with mobile-phone diffusion being more negatively associated with the GII, maternal and child mortality, and more positively associated with contraceptive prevalence among the least- and less-developed countries.

Further analyses adjusting for controls—including panel data fixed-effects models, panel data random-effects models, and instrumental variables (IV) models—corroborate evidence from the above unadjusted associations. For simplicity, we here present results from panel data fixed-effects models only (Table 1), while estimates using different techniques, model specifications, and noninterpolated data are reported in *SI Appendix*, Table S7. We estimate separate models for the four outcomes (GII, contraceptive prevalence, maternal mortality, and under 5 y old mortality) as a function of mobile-phone diffusion, controlling for a host of country-specific covariates such as GDP per capita (Purchasing Power Parity, constant 2011 international dollars), population density, and educational attainment—the share of the population (25 y+ old both sexes) that has at least completed lower secondary education (International Standard Classification of Education 2 or higher). Descriptive statistics on explanatory variables are reported in *SI Appendix*, Tables S3 and S4.

The standardized coefficients reported in Table 1, panel 3 confirm the negative and significant associations between mobile phones, gender inequality, and maternal and child mortality previously described. An increase in mobile-phone diffusion by 1 SD is associated with a decrease in the GII by 0.10 SD ($P < 0.01$), an increase in contraceptive prevalence by 0.06 SD ($P < 0.05$), and a decrease in maternal mortality by 0.01 SD ($P < 0.01$) and in child mortality by 0.06 SD ($P < 0.01$). The sign of the interaction coefficients of mobile-phone diffusion with GDP per capita in categorical form (interaction in continuous form in *SI Appendix*, Table S5) shown in Table 1, panel 3 point to higher absolute returns to technology for less-developed countries documented in Fig. 2, *Right*. Mobile-phone coefficients in Q1 to Q2 countries suggest that mobile-phone technology might serve to complement the role of other development processes such as educational expansion and economic growth, rather than substitute for it.

Coefficient estimates are robust across a variety of estimation techniques and model specifications (*SI Appendix*, Table S7) and also to alternative gender inequality indicators such as the United Nations Development Programme's Gender Development Index, dis-aggregated components of the GII, and the GII indicator purged of the maternal mortality component—an outcome in itself in our analysis (*SI Appendix*, Table S6).

Despite multiple robustness checks, we acknowledge that our ability to make causal claims in the macro-level analyses is limited. Nonetheless, we believe that these analyses offer a global-level overview of the links between mobile phones and indicators of sustainable development. In so doing, the macro-level component of this study paves the way for individual-level analyses focusing on a subset of countries at the low end of the J curve in Fig. 2, toward a more causally oriented understanding of the relationship between technology and sustainable development.

Individual-Level Regional Evidence

In what follows, we provide consistent and more specific evidence from augmented individual-level data in a multilevel perspective. We use nationally representative samples of women aged 15 to 49 y from the Demographic and Health Surveys (DHSs) to study the effects of mobile-phone adoption on (social) sustainable development outcomes. Unlike macro-level data on mobile-phone diffusion, information on individual-level adoption of mobile technologies that can be linked to development outcomes is less readily available (4). The most recent DHS waves in some countries, however, provide data on whether

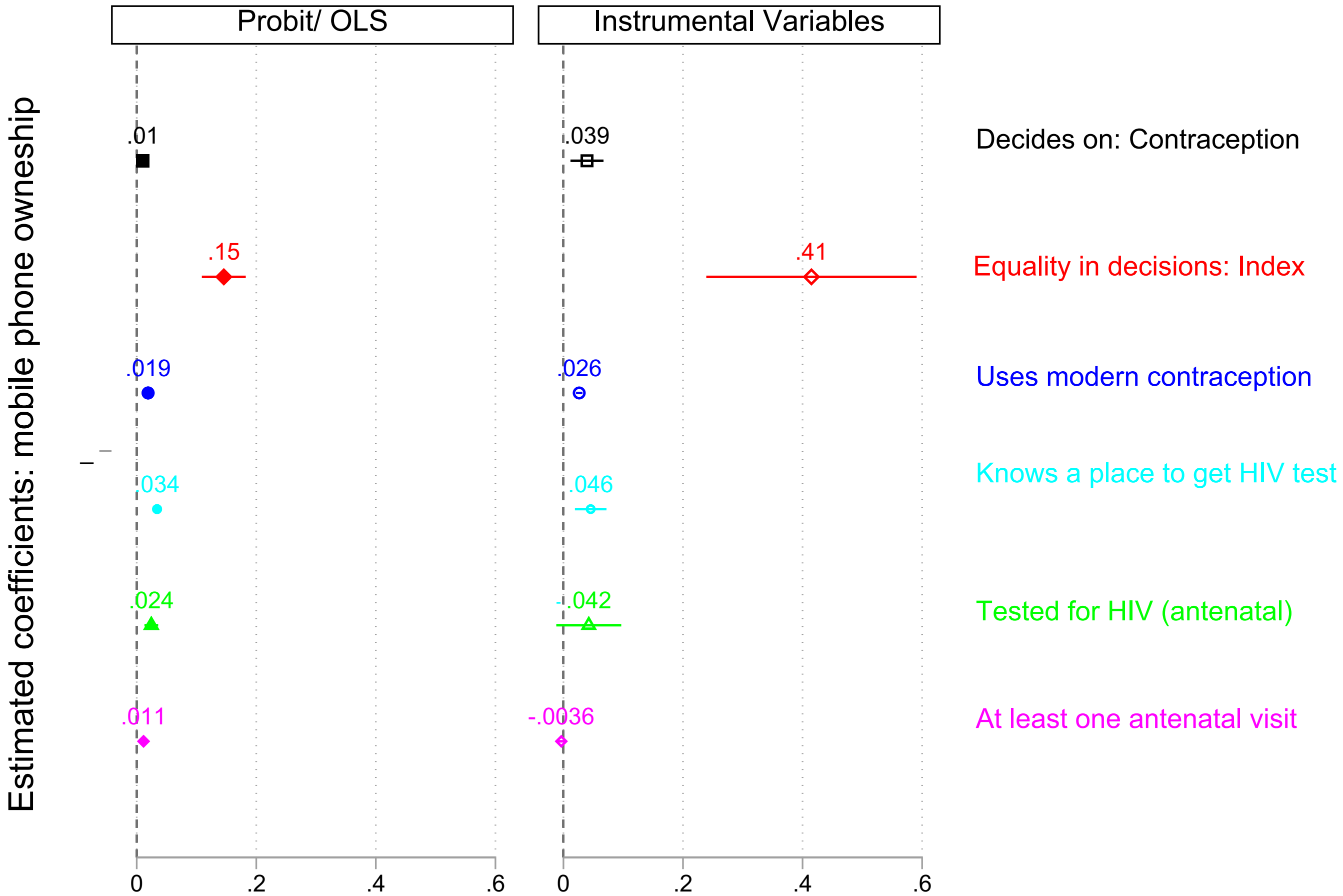

Fig. 3. Individual-level effects of mobile-phone ownership on sustainable development outcomes in sub-Saharan Africa. Shown are coefficient estimates for the effect of owning a mobile phone on outcomes related to women's decision making, knowledge about health-seeking behaviors, and health. Models are estimated on DHS women's samples from seven sub-Saharan African countries (2015 to 2017). Whiskers represent 95% confidence intervals. Covariates used in the models are education, age, household size, employment status, radio and TV ownership, urban, local development (nightlights). Country and year fixed effects are included. SEs are clustered at the cluster level. The bottom two outcomes (tested for HIV and at least one atenatal visit) are estimates from the subset of women who had at least one birth in the last year and for whom we know that the area in which they live was covered by cellular signal in the year preceding the birth. Source: our elaboration from augmented DHS data.

female respondents own a mobile phone and we can exploit this information. The DHSs also contain detailed geographical information about where respondents live, which allows us to augment DHS data with geocoded data. We are therefore able to directly study whether women who own mobile phones are more empowered to make independent decisions in their households, are more knowledgeable about health-seeking behaviors (e.g., where to get tested for HIV), and have improved health outcomes (e.g., contraceptive use, access to antenatal care, etc.).

Individual-level analyses are limited to sub-Saharan Africa (SSA) for two reasons. First, the demographic transition is slowly underway in SSA, with slow fertility decline and infant and maternal mortality remaining at very high levels (33, 34). Relatedly, SSA is the world region with the highest variation in mobile-phone adoption and diffusion.[§] By focusing on SSA we therefore provide evidence from an "extreme-case" scenario where policy interventions related to technology adoption are likely to be particularly effective—as also suggested by the higher marginal returns to technology for less-developed countries documented above. Second, by focusing on a subset of SSA countries we seek to ease comparability and maximize the internal consistency of our findings. In this respect, we are concerned about the potential endogeneity of mobile-phone ownership, our key explanatory variable.

Endogeneity can arise as mobile-phone ownership and social development outcomes might be jointly determined by individual characteristics that are not observed. Similarly, we cannot rule out instances of reverse causality whereby more empowered women are more likely to own a mobile phone. To address these concerns, we select from among the available pool of DHSs those containing 1) information on mobile-phone ownership and 2) GPS coordinates (latitude and longitude) of the respondent's household. Following these criteria, we select DHSs providing individual-level data on women between 2015 and 2017 from seven SSA countries: Angola, Burundi, Ethiopia, Malawi, Tanzania, Uganda, and Zimbabwe. The combined dataset includes more than 100,000 individual observations—for more details on the sample refer to *SI Appendix*, Table S8.

We augment DHS individual-level geocoded data with information from other sources. First, we link DHS data to the degree high-resolution full climatology (HRFC) dataset, which contains information on total lightning flash rates seen by the space-borne optical transient detector (OTD) and lightning imaging sensor (LIS). Second, we link DHS data with Afrobarometer data,

[§] The coefficient of variation (CV) based on ITU data for Africa is equal to 135.39, against a CV of 117.65 for Asia, of 71.25 for Europe, of 100.12 for the Middle East, and of 95.72 for North and South America.

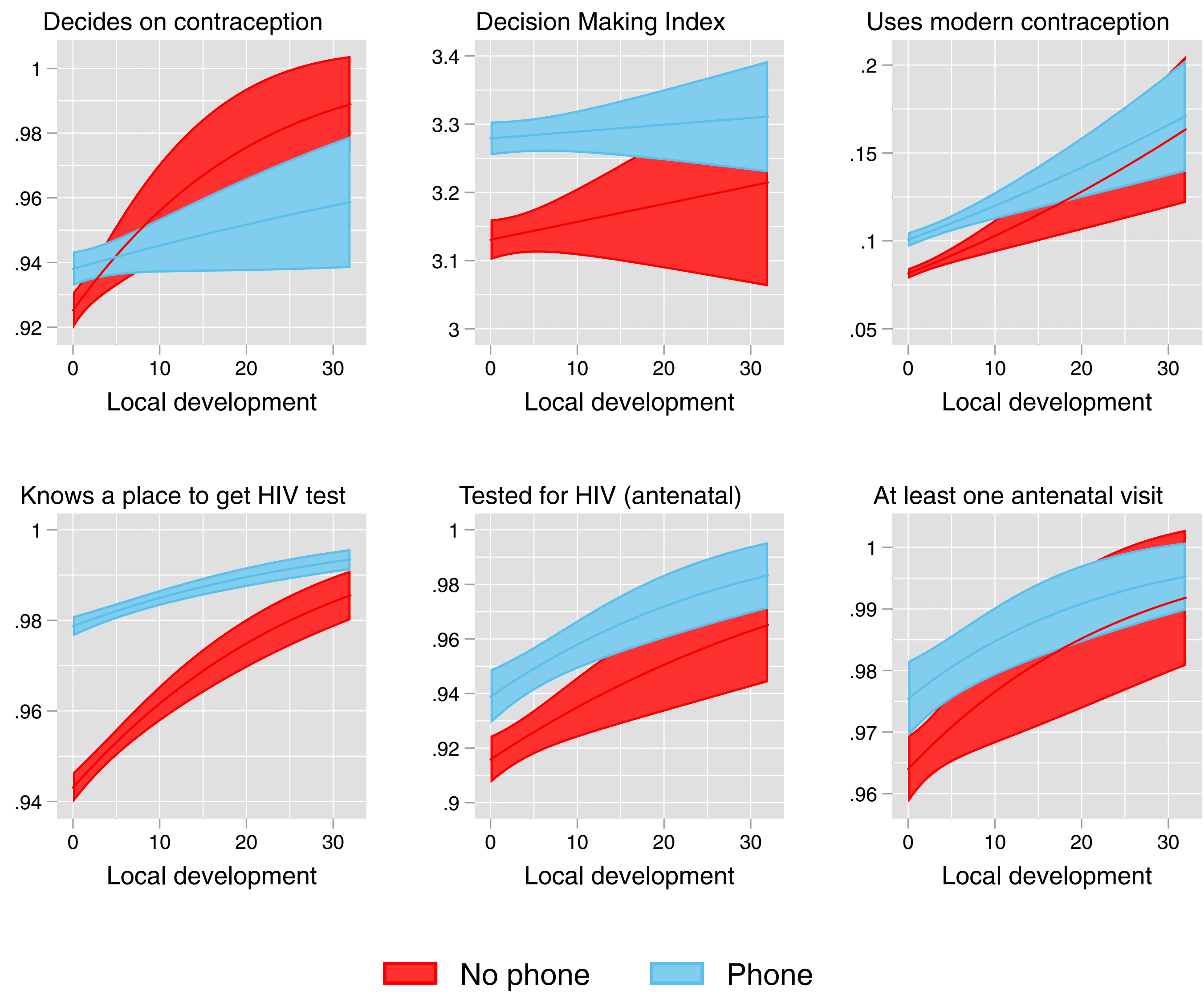

Fig. 4. Marginal effects of the interaction between mobile-phone ownership and local development. The plots show the marginal effects of the interaction between mobile-phone ownership and local development as proxied by nightlights. Spatial information is converted into a scale (0 to 60, here truncated at 30 for visual purposes) whereby lower values correspond to lower development and higher values correspond to higher development (note that the scale itself does not matter). Source: our elaboration from augmented DHS data.

exploiting the fact that survey enumerators in the Afrobarometer recorded the availability of specific facilities, including mobile-phone coverage in the local geographical unit of the respondent. This innovative use of linked data enables us to 1) devise a solid identification strategy, as mobile-technology adoption is slower and connectivity is weaker in areas where lightning strikes are more frequent—likely due to damaged antennas on the ground (similarly to ref. 35)—and 2) exploit information about mobile-phone coverage in the area where the respondent lives. These data allow us to obtain individual-level instrumental-variable estimates of the effect of mobile-phone ownership on sustainable development outcomes.

An important issue that still hampers the causal interpretation of the estimates is that access to technology might mask wider developmental processes unfolding at the local level. We work around this potential bias by further linking augmented DHS data to the visible infrared imaging radiometer suite (VIIRS) nighttime imagery dataset, which contains information about nighttime lights, a well-established proxy for local development (36, 37). We then include this proxy in our model specifications while keeping the level of granularity of the analysis unaltered.

To summarize, our final augmented DHS dataset includes information from four different datasets that are linked through GPS coordinates. As all data are publicly available (*SI Appendix*, Table S1), our analyses are easily replicable.[¶] *SI Appendix* provides additional descriptions of the data (*SI Appendix*, Table S8), variables (*SI Appendix*, Table S9), and methods used in this individual-level analysis.

Fig. 3 plots the estimated coefficients from a series of ordinary least-squares (OLS) or probit (Fig. 3, *Left*) and instrumental variables regression models (Fig. 3, *Right*). We regress four sets of outcomes on mobile-phone ownership, namely 1) women's involvement in intrahousehold decision making regarding contraception (1a) or women's involvement in intrahousehold decision making as measured by a linear index comprising decisions

[¶]DHS datasets can be downloaded directly from http://dhsprogram.com.

on health, household large purchases, and visits to family and friends (1b); 2) women's actual use of modern contraceptive methods; 3) women's knowledge of health-related outcomes and, specifically, of where to get tested for HIV; and, eventually, 4) information on women's antenatal visits' quality during the last pregnancy, proxied by either whether a woman has been tested for HIV (4a) or whether she has undergone at least one antenatal visit (4b). For the last two outcomes we include only women who had at least one birth in the last year and for whom we know that the area in which they live was covered by cellular signal in the year preceding the birth. This information is obtained by combining the interview date and the geographical location of the DHS birth-history data and the Afrobarometer. Alongside the aforementioned proxy for local development (nighttime lights), all models account for standard socioeconomic controls—respondent's education, age, household's size, employment, and urban/rural status[#] —together with indicators of exposure to other media (radio and TV). Models also include country and year fixed effects to account for unobservable country-level heterogeneity.

Results indicate that women who own a mobile phone have higher probability of being involved in decision-making processes about contraception ($\beta = 0.01$; $P < 0.01$), higher overall decision-making power within the household ($\beta = 0.15$; $P < 0.01$), higher likelihood of using modern contraceptive methods ($\beta = 0.02$; $P < 0.01$), and a higher likelihood of knowing where to get tested for HIV with respect to women who do not own a phone ($\beta = 0.03$; $P < 0.01$). Estimated coefficients are sizable, as for most outcomes the effect of owning a mobile phone is roughly comparable to—if not bigger than—that of living in an urban area. Results are robust to the use of instrumental variables, thus adding confidence in the interpretation of the coefficients as causal estimates. Mobile-phone ownership is also associated with a higher chance of being tested for HIV during pregnancy ($\beta = 0.02$; $P < 0.01$) and to a higher chance of having undergone at least one antenatal visit ($\beta = 0.01$; $P < 0.01$), yet IV results do not allow us to interpret these last two associations as causal as the estimated coefficients are not statistically significant.

Finally, to parallel the macro-level analyses of heterogeneous effects by level of development, Fig. 4 reports the marginal effects of the interaction between mobile-phone ownership and local development measured through nightlights at the cluster level. Results show significant differences in social development outcomes between women owning (blue) versus not-owning (red) mobile phones, but only at lower levels of local development, i.e., where the two bands do not intersect. Differences are particularly noticeable for the decision-making index, use of modern contraceptive methods, knowledge of a place to get HIV testing, and actual HIV testing. Clusters with low local development are typically those that characterize remote areas with poor infrastructure and connection to big cities, thus making mobile phones a powerful tool to enhance access to information and service accessibility relative to higher-local-development areas where alternative means make information more readily available. These findings confirm once again the higher payoffs to technology adoption in less-developed micro-level clusters. For full-model estimates for each outcome, together with sensitivity tests, refer to *SI Appendix*, Tables S10–S17.

Conclusions and Outlook

By combining a wide range of datasets, this study has provided large-scale evidence on the positive associations between mobile phones and several key sustainable development indicators. Our macro-level global analyses have shown how the diffusion of mobile phones across countries over time is associated with lower gender inequality, higher contraceptive uptake, and lower maternal and child mortality levels. Importantly, associations are strongest in absolute value for countries in the lowest quintiles of development (following a J or reversed-J shape), a finding—further corroborated through micro-level analyses—which highlights the importance for policymakers around the globe to close digital divides as a way to foster sustainable development. Although we acknowledge that our ability to make causal claims in the macro-level analyses is limited, we see this global-level overview as an essential building block toward a holistic understanding of the relationship between technology adoption and sustainable development. Further research is needed to unravel and understand the mechanisms that underlie these macro-level relationships, thus providing effective guidance to practitioners.

Our individual-level analyses for sub-Saharan Africa have shown how women who own a mobile phone are better informed about where to access sexual and reproductive health and are better able to make their own decisions in their households, including about contraception. Through these channels of improved knowledge and enhanced decision-making power, our individual-level analyses have suggested a pathway through which the macro-level results emerge. The macro- and individual-level analyses provide consistent and complementary results that support each other to understand the broader implications of the digital revolution on social development processes.

More than 20 y ago in 1995, the Beijing Declaration and Platform for Action reaffirmed that the human rights of women and girls are an inalienable, indivisible, and integral part of the universal human rights. Since then, gender equality has been acknowledged as both a standalone SDG and one that is inextricably linked with progress on other SDGs, including key targets associated with health and well-being (38). Since the 2000s, considerable improvements have been observed through SDG indicators such as contraceptive use and under 5 y old mortality (39). Our study has highlighted how these improvements have been bolstered, among other factors, by the digital revolution, and in particular by the diffusion of mobile phones. Echoing the words pronounced in 2003 by Nobel Peace Laureate Muhammad Yunus at a conference on poverty and ICTs (40), "the quickest way to get out of poverty right now is to have one mobile telephone." This study has provided strong empirical support that boosting mobile-phone access and coverage, and crucially overcoming digital divides and ensuring equitable access to these technologies, is indeed one powerful instrument to get closer to the attainment of the sustainable development goals.

Still, despite the proliferation of mobile networks, digital divides by gender and socioeconomic strata persist in the developing world. Women are less likely to own mobile phones on their own, use them less often when they have access, and have poorer ICT skills compared to men, thus creating second-level (skill-related) digital divides on top of first-level (access-related) ones (33, 41–44). Given that the costs associated with mobile phones are still significant, those with lower income and education, including women, are less able to access and use mobile phones (41, 45). The full potential of mobile technologies thus cannot be wholly exploited if digital divides persist. Investing in cheaper equitable access, enabling independent ownership, and focusing on ICT skill development, especially among women, can forge an even more promising pathway to leverage mobile phones for attaining sustainable development.

Materials and Methods

The methods used along with the empirical analyses are described in detail in *SI Appendix* and include panel data fixed effects, random effects, and instrumental variables models for global macro-level analysis and OLS,

[#]As a robustness check we also account for wealth at the household level. Results are robust to the inclusion of this control (*SI Appendix*, Table S16).

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multilevel, probit, and IV models for the individual-level regional analysis. The macro-level dataset and codes needed to link the micro-level data are deposited in the Open Science Framework data collection (https://osf.io/27ktq/). Macro- and micro-level data come from different data sources, as detailed in *SI Appendix*, Table S1.

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