Pontifícia Universidade Católica do Rio de Janeiro

Amanda de Albuquerque Jardim Rocha

Essays on Development Economics and Public Policy: Sustainable Agriculture, Management in Health, and Political Accountability

Tese de Doutorado

Thesis presented to the Programa de Pós–graduação em Economia, do Departamento de Economia da PUC-Rio in partial fulfillment of the requirements for the degree of Doutor em Economia.

Advisor : Prof. Juliano Assunção
Co-advisor: Prof. Claudio Ferraz

Rio de Janeiro
September 2022

Pontifícia Universidade Católica do Rio de Janeiro

Amanda de Albuquerque Jardim Rocha

Essays on Development Economics and Public Policy: Sustainable Agriculture, Management in Health, and Political Accountability

Thesis presented to the Programa de Pós–graduação em Economia da PUC-Rio in partial fulfillment of the requirements for the degree of Doutor em Economia. Approved by the Examination Committee:

Prof. Juliano Assunção
Advisor
Departamento de Economia – PUC-Rio

Prof. Claudio Ferraz
Co-advisor
Departamento de Economia – PUC-Rio

Prof. Cecília Machado
Escola Brasileira de Economia e Finanças - FGV EPGE

Prof. Paula Pereda
Universidade de São Paulo

Prof Edson Severnini
Carnegie Mellon University

Prof. Ursula Mello
Barcelona School of Economics

Rio de Janeiro, September 22nd, 2022

Amanda de Albuquerque Jardim Rocha

M.A in Economics (PUC-Rio, 2015), B.A. in International Relations (UnB, 2011). Co-founder *Rede A Ponte*.

Bibliographic data

Rocha, Amanda de Albuquerque Jardim

Essays on Development Economics and Public Policy: Sustainable Agriculture, Management in Health, and Political Accountability / Amanda de Albuquerque Jardim Rocha; advisor: Juliano Assunção; co-advisor: Claudio Ferraz. – 2022.

150 f: il. color. ; 30 cm

Tese (doutorado) - Pontifícia Universidade Católica do Rio de Janeiro, Departamento de Economia, 2022.

Inclui bibliografia

1. Economia – Teses. 2. Economia do Desenvolvimento. 3. Políticas Públicas. 4. Agricultura Sustentável. 5. Gestão em Saúde. 6. Protestos. I. Assunção, Juliano. II. Ferraz, Claudio. III. Pontifícia Universidade Católica do Rio de Janeiro. Departamento de Economia. IV. Título.

CDD: 620.11

To Tiago Flórido, *in memoriam*

Acknowledgments

I begin by thanking all funders who believe in Science and encourage research in this country. I thank Capes, CNPq and FAPERJ, which financed different phases throughout these 4.5 years of my PhD. I also thank Fulbright for granting me the scholarship to carry out my visiting period in UC Berkeley. Special thanks to Instituto Escolhas, for granting me a scholarship for 2 years. In addition to helping me to support myself financially, this ended up becoming a commitment to myself: I'm going to do research on sustainable agriculture. And I did! How wonderful it is to be able to write this now at the finish line. Learning to celebrate in the academic environment was a valuable lesson for me, as we are constantly criticizing so science and knowledge can move forward.

I experienced many processes during my PhD. The most difficult of them, without a doubt, was trusting myself. Trusting the message I wanted to convey, trusting the ability I have, trusting the opportunities the universe has given me and embracing them. Embracing them without carrying the feeling that it was by luck, but knowing that I represent the story of many, many people that came before me. Each one carries within itself the achievements of generations and generations. And it takes seriousness to recognize and honor that.

Therefore, I always thank them, my family, my base, my support. I begin by honoring my elders. My grandma Eloina, my grandpa Deda, who raised a mother with such strength and determination. I thank my grandma Enny, my grandpa José, who raised such a dedicated father. Thank you for all unconditional love, for all inspiration and for all faith. May I honor our family's journey and also take care that the seeds that will come carry the virtues passed on to me.

To my mother, for being a source of eternal inspiration of freedom and recognizing the ephemeral and wonderful opportunity that we have to be alive here today.

To my father, for teaching me that taking care is better than fighting. For planting the seed of generosity so firmly as this is an essential virtue to be cultivated, in all places and contexts.

To Angela, my sister by blood and soul, who knows me like no one else and has always been a safe harbor in the most challenging moments. Thank you for all your loyalty and precious teachings.

To Mateus, for being firm in his convictions, and for sticking to the truth like few others I know. For your eternal and genuine curiosity. And for the good fight of ideas, which once again forced me to establish myself in what I am and believe in.

To my advisors, for all their patience and perseverance. This work would not have been possible without your full support.

To my co-authors on paper 3, Laura and Helena, who allowed me to state the way I want to do research: together, with commitment and with open communication. You give me hope that the urgent change in academia is possible. And it's already happening.

To my co-authors of paper 1, Arthur, Ricardo and Juliano, who did not lose faith in the message I wanted to convey and who helped me to shape it and get to a concrete form. How lucky I am to be able to work on such an important project for me with amazing people that I admire so much.

To the members of the examination committee, I am immensely grateful for their generosity of time and valuable comments that enhanced this work. It is an honor to be able to count on a diverse panel, with researchers that I admire and with whom I learn so much.

To my colleagues (and family) that I made on the very long journey that was the project in Mozambique. Janeth, Sandra, Maggie, Maria and Yara, working on a project in health in the middle of a pandemic, I relearned the golden lesson: it's all about the team! Thank you for all your strength and firmness. Against a sea of obstacles, we did it.

To Fred, who challenged me to show up and position myself. And who gave me hope once again in academic research. And to Francesco. "You need to own it!", this phrase will always echo in my mind.

To the best RA I could dream of finding, Claudinei dos Santos. Thank you for so much patience, delivery and generosity. And better late than never, to my friend Arthur Aguillar, for providing me with the G1 data base on the 2013 protests during my Masters.

To the professors of the Dept. with whom I could exchange and learn about issues other than research, Gustavo Gonzaga, Marcelo de Paiva Abreu and Nathalie Gimenes. To the dear, precious administrative staff who have always supported me and brightened my day to day, Bianca, Pri, Bruna and Roseli.

To the sisters on my path, who calmed my heart and celebrated every step taken: Priscila Minervino, Mariana Carvalho, Luisa Cardoso, Bia Vasconcellos, Chris Szerman, Carolina Hamburguer, Dominique, Nish, Joana Borges, Yara Ribeiro, Erica Capella, Janeth Dula, Franceca Cancelliere , Viviane Pereira, Luciana de Deus, Beatriz Cunha, Fabiana Arake, Thais Castro, Gabriela Manara, Lia Guazzelli, Hanne Reis, Gabriela Carvalho, Racquel

Stepanski, Maju, Courtney Ivins, Sara Brolhato, Carol Kang, Mariam Ashad, Camila de Sá, Joyce Soares, Nathalia Muguet, Tita Tepedino, Jen Ching, Rita Schroeck, Paula Torelly, Olivia Ferreira.

To my sister-wife, who co-founded A Ponte together with me. Mari Carvalho, thank you for your strength and for being a fertile soil for me to always remember the power of our dreams.

To my beloved friends, for being patient in the difficult task of putting my foot on the ground: Fernando Mattar, Thales de Freitas, Muheti, Marcelo Sumi, Pedro Tepedino, Marcelo Sena, Joao Pedro, Luis Felipe Lopez, Harmen, Januario Faustino, João Tavora, Gabriel Granato, Raffael Russo, Marcio Firmo, Rodrigo Fiaes, Marcos Simeao, Beto Cragno, Thiago Scot, João Neto, João Moura, João Morgado, Guillaume Coquet, Arthur Aguillar, Caue Dobbin, Pedro Tanure.

Special thanks to the friend who had to put up with me daily at these final months. Gustavo Pinto, thank you for being the most beautiful example of the word *partnership* and *friendship*.

To the incredible women I connected with on this journey: Debora Thome, Laura Karpuska, Joana Monteiro, Mayara Felix, Rhaysa Ruas, Marina Palma, Paula Pedro, Livia Govea, Maina Celidonio, Laura Schiavon, Synthia Santana, Carolina Grottera, Paula Pereda, Cecilia Machado, Ariana Britto, Diana Moreira, Ieda Matavelli, Julia Fontes, Natalie Victal, Thais Custodio, Renata Canini, Ursula Melo e Marina Hirota.

I end here with an appeal. Many things need to change on academia so that women feel welcome to step up and occupy more space. To feel free and thus bring new ideas and share a different perspective of the world. The academic environment is still very hostile to us. We need less formality in relationships, recognizing that we are all human with lives beyond work. It is necessary to give the benefit of the doubt in an environment that still tends to favor men. We need to talk more, connect more, understand more. Collaborate and cooperate. Understand that, most of the time, it's not about right and wrong, but about building up things together. Humanity has never depended and will never depend on a single person individually. May we stop missing the opportunity to generate useful and necessary knowledge for society in the name of intellectual vanity.

For those yet to come, I hope the academy doesn't take so long to change. That more and more the *gatekeepers* take care of you and do not turn a blind eye to offenses of any kind. That high quality research does not mean green light to commit bullying. That the metric of success will no longer be merely publication – even more so when we know how the publication process is contaminated by networking which causes serious barriers to diversity.

That those yet to come feel safe and find space to be freer. The world needs to hear what you have to say.

And, of course, "if I had more time, I would have written a shorter letter". Thankful for so much.

** This research was financed by: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001; CNPq - taxa de bancada; FAPERJ - Nota 10; Instituto Escolhas - Cátebra de Meio Ambiente; Fulbright - DDRA.*

Abstract

Rocha, Amanda de Albuquerque Jardim; Assunção, Juliano (Advisor); Ferraz, Claudio (Co-Advisor). **Essays on Development Economics and Public Policy: Sustainable Agriculture, Management in Health, and Political Accountability**. Rio de Janeiro, 2022. 150p. Tese de Doutorado – Departamento de Economia, Pontifícia Universidade Católica do Rio de Janeiro.

This thesis is composed of 3 chapters in development economics, all of which relate to the role of public policy either in promoting sustainable policies for long-run maintenance of natural resources, or meeting citizens' needs through efficient service delivery or questioning the accountability of current political institutions. The first paper shows that, by adopting a technology that incorporates sustainable agricultural practices, farmers have positive dynamic effects on productivity and climate resilience. We provide evidence of the mechanism of these dynamic effects: soil improvement. The second one presents the results of an RCT designed to test whether a managerial intervention in health centers in Mozambique can reduce coordination failures, increasing HIV patients' retention in care and quality of care provided. Finally, the third one look at the large street protests that took place in Brazil in 2013 to analyze whether protests can work as an accountability mechanism for elected politicians. Using Twitter historical data, we create a measure of protest intensity and how noisy protesters' demands were in each municipality. We present evidence that protests may work as accountability mechanism only if messages sent by protesters are sharp and clear, and politicians face reelection incentives.

Keywords

Development Economics; Public Policy; Sustainable Agriculture; Management in Health; Protests.

Resumo

Rocha, Amanda de Albuquerque Jardim; Assunção, Juliano; Ferraz, Claudio. **Ensaios sobre Economia do Desenvolvimento e Políticas Públicas: Agricultura Sustentável, Gestão em Saúde e Responsabilidade Política**. Rio de Janeiro, 2022. 150p. Tese de Doutorado – Departamento de Economia, Pontifícia Universidade Católica do Rio de Janeiro.

Esta tese é composta por 3 capítulos em Economia do Desenvolvimento, todos eles relacionados com o papel das políticas públicas, quer na promoção de políticas sustentáveis para a preservação de recursos naturais no longo prazo, quer na prestação de serviços públicos eficientes ou no questionamento do *accountability* das atuais instituições democráticas. O primeiro artigo mostra que, ao adotar uma tecnologia que incorpora práticas agrícolas sustentáveis, os agricultores têm efeitos dinâmicos positivos na produtividade e na resiliência climática. Apresentamos evidências do mecanismo dessas externalidades: melhorias no solo. O segundo artigo apresenta os resultados de um RCT desenvolvido para testar se uma intervenção gerencial em centros de saúde em Moçambique pode reduzir falhas de coordenação, aumentando a retenção de pacientes com HIV ao tratamento e a qualidade do atendimento prestado. Por fim, o terceiro analisa os grandes protestos de rua ocorridos no Brasil em 2013 para analisar se os protestos podem funcionar como mecanismo de *accountability* de políticos eleitos. Usando dados históricos do Twitter, criamos uma medida da intensidade dos protestos e quão ruidosas foram as demandas dos manifestantes em cada município. Apresentamos evidências de que os protestos podem funcionar como mecanismo de responsabilização apenas se as mensagens enviadas pelos manifestantes são nítidas e claras e os políticos enfrentam incentivos à reeleição.

Palavras-chave

Economia do Desenvolvimento; Políticas Públicas; Agricultura Sustentável; Gestão em Saúde; Protestos.

Table of contents

List of figures

List of tables

"E quando a dor vem encostar-se a nós,
enquanto um olho chora, o outro espia o tempo
procurando a solução."

Conceição Evaristo, *Olhos d'Água*.

1 Introduction

This thesis is composed of 3 essays in development economics, aimed to directly contribute to the debate on different areas of public policy and institutions.

The first essay shows that, by adopting a technology that incorporates sustainable agricultural practices, farmers have positive dynamic effects on productivity and resilience. There is a large body of empirical research in social sciences studying the effects of the environment on agriculture. However, there is much less evidence on the effects of agriculture on the environment despite growing recognition that agricultural practices influence soil properties, affecting productivity and resilience. Chapter 2 documents dynamic effects associated to sustainable agricultural practices which affects productivity in the state of Mato Grosso (Brazil) – an agricultural hub of global importance. Specifically, we use within-farm variation on the timing of adoption of double cropping to examine it dynamic effects on soil quality, climate resilience, and, ultimately,

Our analysis explores rich satellite-based information on technology use, productivity soil properties, and fire incidence. First, we document that the length of exposure to double cropping increases productivity. Second, we tie this increase in productivity to changes in soil properties: longer exposures to double cropping increase soil's ability to store carbon and water. Third, we document that these changes in soil properties lead to lower fire incidence. Our results have immediate consequences for public policies. Reconciling food production and climate change mitigation requires identifying technologies that simultaneously increase productivity, carbon sequestration, and climate resilience. Our findings indicate the potential of double cropping for achieving these three goals. This has the potential of reverting some of the negative effects of climate change on agriculture and well as to help it to become a leading sector in climate change mitigation.

The second essay presents results of an RCT designed to test whether a managerial intervention in health centers in Mozambique can reduce coordination failures, affecting HIV retention in care, utilization of antenatal care services and improving quality of care. Provision of health services is one of the greatest challenges for the government of Mozambique, being one of the countries with the highest HIV prevalence in the world (12.3%) and worst maternal mortality rates. Even though the country has overcome challenges in initially enrolling patients in treatment, patients' retention to treatment is currently a major barrier to control the spread of HIV - only 66% of patients who start treatment remain active after 12 months of enrolling in treatment. We hypothesize that poor quality and general unresponsiveness of services provided at public health clinics can be an important reason for low patient retention to treatment. Through an RCT at 80 health centers, we tested whether a managerial intervention that implemented an appointment scheduling could increase patients' adherence to medical treatment and also improve quality of care from the providers' side. We find heterogeneous effects, with the intervention affecting more positively patients enrolled for longer periods in antiretroviral therapy (ART) treatment. Moreover, even though patients do not report improvements in their perception on their patient experience visiting the facility, we see relevant improvements in performance of clinical procedures during antenatal care visits.

This research significantly enhances the global knowledge about strategies to address the long-standing problem of long waiting time for care in public health clinics in Sub-Saharan Africa. The problem of mismanagement of patient inflows at public clinics goes well beyond the Mozambican context. From a cost-effectiveness viewpoint, the proposed intervention is very timely as countries in the developing world face the prospect of increased patient flows into already strained health systems. Particularly for HIV, the universal move towards a WHO-endorsed test-and-start strategy that requires starting all patients on treatment immediately after an HIV-positive diagnosis is already adding considerable pressure on Mozambique's health system. The findings from this research are therefore likely to have important policy implications for other health systems in low and medium-income countries, as it is easily scalable and transferable to other areas of health care provision, requiring minimal staff training and limited financial resources.

Finally, the third one look at the large street protests that took place in Brazil in 2013 to analyze whether protests can work as an accountability mechanism for elected politicians. Using Twitter historical data, we create a measure of protest intensity and how noisy protesters' demands were in each municipality, and measure federal legislators' response to protests. Despite the increasing occurrence of street protest, it is still unclear if they have been successful to work as an accountability mechanism. We propose a theory of protests as a Bayesian persuasion mechanism and we ask what are the conditions such that protests can be a successful tool for accountability. We think about accountability in two ways. First, we see accountability purely as persuasion, as incumbents responding to the demands from the street. Secondly, we think about accountability in the sense of citizens reelecting incumbents that are responsive to voters demands with higher probability. Our model shows that protests that do not have a clear demand – and so face a noisy communication channel, are not only less successful, but they can be ex-ante inefficient as persuasion mechanism. Interestingly, noisy protests help to separate politicians that deliver the demands from the street from the ones that did not deliver, improving electoral accountability. We take the model's findings to the data. We empirically analyse the effects of the large street protests that took place in Brazil in 2013 in both voters and federal legislators behavior. Using twitter historical data, we compute a measure on how noisy protesters' demands were in each municipality. Consistent with the model, we find that noisier protests are less effective in persuading politicians to allocate resources to protests demands, showing there is empirical evidence that protests are less effective as an accountability mechanism in the persuasion sense.

2
Reconciling Environmental Sustainability and Agricultural Productivity: Evidence from Double-Cropping in Brazil

Amanda de Albuquerque (PUC-Rio)
Juliano Assunção (PUC-Rio)
Arthur Bragança (PUC-Rio)
Ricardo Dahis (PUC-Rio)

Abstract

Standard models in agriculture economics assume the soil to be a fixed input of the production function. In this paper, we document how agricultural practices indirectly affect soil quality, climate resilience, and, ultimately, long-term productivity. Using rich satellite data, we explore within-farm variation in double-cropping, a practice increasingly adopted in Brazil's biggest crop producer state (Mato Grosso), to show that its adoption increases water availability, soil carbon, and productivity. We further provide evidence that double cropping decreases fire occurrence. We explore the intensive margin rather than the intensive one and find that all the effects are increasing in the number of years of exposure to double cropping. These results are consistent with exposure to double cropping having dynamic effects on soil quality and resilience.

2.1
Introduction

There is a large body of empirical research studying the effects of the environment on agriculture. However, there is much less evidence on the effects of agriculture on the environment (Dias et al. (2019)). This paper contribute to the growing literature that shows that agricultural practices affect environmental outcomes, affecting thus productivity. As both food security and climate change become more pressing issues globally, it is important to bring evidence on the use of technologies that increase productivity, enhance resilience to climate change, and reduce the GHG emissions.

In this paper, we estimate the dynamic effects associated with the use of agricultural practices in Brazil. Agricultural economics typically treats soil as exogenous and static input in the production function (Mendelsohn et al. (1994). Broader use of soil quality as control in other research fields also does consider that the soil is fixed, not considering that its properties can change in the short-run (Bustos et al. (2016)). However, a growing body of research from biological sciences suggests that the soil is a complex and dynamic structure which is influenced by land use and agricultural practices. Because soil is one of the key inputs in the agricultural production function, it is therefore fundamental to empirically investigate whether technologies and practices influence this input and how it affects farmers' productivity and climate resilience.

Historically, single-cropping has been the main technological choice in most crop producer countries. Classical trade theories, that advocate for specialization, account this on scale gains with standardization (during planting, management and harvesting), enhanced by technological advances in mechanization, chemical fertilizers and genetic engineering. Nonetheless, single-cropping has also proved to dismantle soil properties, by decreasing nutrient cycling and increasing erosion rates. The depletion of some soil properties impacts crops' productivity, adding pressure on farmers to land conversion from forest to cropland. Moreover, landscape simplification presents strong effects on regulation of ecosystem services such as biological regulation services and biodiversity (Bianchi et al. (2006); Rusch et al. (2016); Tscharntke et al. (2005)).

Here, we focus on the adoption of double-cropping, a widespread technology used in Mato Grosso, Brazil's main agricultural hub and responsible for the production of 8% of the world's soybeans (Roy et al. (2016)). Mato Grosso makes an interesting place to study as it is one of the world's most extensive agricultural frontiers, being the largest state of Brazil, with an area of 90.3 million ha. Double-cropping has become increasingly popular among Brazilian farmers in the past 30 years. It basically means that two different crops are planted in the same plot during an agricultural cycle (1 year) in a staggered way. In this paper, we use data that combined machine learning and satellite data to create measures of double-cropping adoption at the 250m pixel level.

To empirically measure dynamic effects related to this technology, we need to overcome the challenge that technology adoption is endogenous to farmers' characteristics (such as know-how and credit access) and farms' characteristics (market access and soil properties). Using a detailed dataset from satellite images from Mato Grosso, Brazil's biggest crop producer, we count on a rich set of controls that allow us to clean our analysis from bias due to self-selection on technology adoption. Our results are identified by making comparisons of different plots within the same farm, thus cleaning out the effect of farmers' characteristics that would confound the effect of the technology on our outcomes. Our identification comes from comparing how different time exposure to the treatment (double-cropping) has different impacts on agricultural and environmental outcomes. Our results show that, conditional on adopting the technology, double-cropping has positive effects on productivity and fire resilience.

We draw from the increasingly available satellite data (Donaldson and Storeygard (2016); Burke and Lobell (2017); Jain et al. (2019); Lee et al. (2020); Kubitza et al. (2020)) to build a rich pixel-level panel connecting double-cropping, evapotranspiration, plants' carbon uptake, vegetation health index, and fire occurrence. We then exploit within-farm variation in length of adoption of the double-cropping technology to estimate its effects on the various outcomes. We begin by documenting that longer exposure to double-cropping leads to a small average increase in the vegetation health index (Normalized Difference Vegetation Index, NDVI) for crops during the first harvest, but a large one during the second harvest. We then show this increase in productivity is connected to changes in soil carbon and water availability. One additional year under double-cropping leads to about a 1.4% increase in plants' carbon uptake and a 3.4% increase in evapotranspiration. We further document a large negative 14.8% effect of accumulated double-cropping on fire occurrences at the pixel level.

Providing rigorous evidence that this sustainable technology generates positive impacts due to its dynamic effects on soil features is the main contribution of this paper. Large-scale assessment of the relation between double-cropping and soil quality and productivity is missing. Previous studies have shown that double-cropping can increase yields due to improved soil conditions (dos S. Cordeiro et al. (2021); Pereira et al. (2007); Nivelle et al. (2016); Williams et al. (2018); da Silva et al. (2020)). Improvements in soil fertility are the result of increases in soil organic carbon and soil aggregate stability, which protects soil from runoff of sediments and nutrients into waterways. However, most of the studies implement experiments in a restricted number of field sites (Tadesse et al. (2021); Williams et al. (2018); Mitchell et al. (2015); Dean and Weil (2009); Laloy and Bielders (2010); Gaudin et al. (2015); Blanco-Canqui et al. (2015)).

The mechanism we explore here is the connection between the water and the carbon cycles. As carbon stocks in the soil rise, there are improvements in soil structure due to root and microbiological development (McDaniel et al. (2014)), which affects aeration and water-holding capacity. Thus, besides positive effects on fertility, double-cropping can improve water infiltration, which will then affect plots' resilience to natural fire occurrence, a phenomenon typical in Mato Grosso during the dry season.

The mechanism we find here is that the technology is capable of affecting relevant inputs of the production function. Water availability in the system seems to be the key driver of the positive effects. As the soil changes its structure after years implementing "conservative agriculture" practices present on double-cropping technology it increases its capacity of water retention.

This paper contributes to a few strands of literature. First, most of the literature that connects climate change and agriculture goes in the direction of measuring how the environment affects agriculture: mainly, how changes in the temperature and rainfall and occurrence of extreme climate events affect agricultural production (Assunção and Chein (2016); Schlenker and Roberts (2009); Auffhammer et al. (2006); Schlenker and Lobell (2010); Welch et al. (2010); Carleton and Hsiang (2016); Auffhammer and Schlenker (2014)). Research focus on yields alone may miss the assessments of agriculture vulnerability to climate change in broader terms, such as cropland available area (Hornbeck (2012); Rattis et al. (2021)), cropping frequency (Cohn et al. (2016)) and quality of crops (Dalhaus et al. (2020)).

We present evidence to balance the knowledge in the opposite direction: how agriculture affects the environment? Most papers looking on the impact of agriculture on the environment focus on how pressure to expand the agriculture frontier leads to deforestation (de Sá et al. (2013); Kastens et al. (2017); Nepstad et al. (2014); Song et al. (2021)). Massive native vegetation loss (such as the 50% loss of Cerrado biome in Mato Grosso since 1970) translates into change in rainfall, which reflect back on agricultural productivity by shortening the growing season (Spera et al. (2020); Leite-Filho et al. (2019); Leite-Filho et al. (2021); Araujo (2021)). These results point out to the increasing risk farmers may face in the near future as clearing of natural vegetation can create a regional climate that hinders the successful cultivation in rain-fed systems.

Nonetheless, deforestation and water cycle disturbance do not encompass all negative environmental externalities agriculture can bring to the environment. There are key ecosystems services that are at stake, such as carbon sequestration (Sommer and Bossio (2014); Smith et al. (2008); Lal (2011); Paustian et al. (2016)), preservation of biodiversity and genetic material of flora and fauna (Kehoe et al. (2017); Zabel et al. (2019); Wätzold et al. (2016)), and water quality (Dias et al. (2019); Elbakidze et al. (2022); Taylor and Heal (2021); Schläpfer and Erickson (2001)). We contribute to this literature by documenting positive externalities of sustainable agricultural practices on resilience to fire occurrences.

Our work also relates to the literature on technology adoption in agriculture. The majority of research provides analysis at the extensive margin, modeling the drivers of farmers' decision to adopt or not a new technology. Providing estimates of partial equilibrium effects, a major challenge on the micro-empirical studies in the intersection of agriculture and the environment (Jayachandran (2022)), a gap is presented here on what is the effect of the proposed technology not only on agricultural output, but environmentally and in the long-run, as most of the proposed interventions apply techniques on single-cropping systems (Duflo et al. (2011); Emerick et al. (2016); Hanna et al. (2014); McArthur and McCord (2017); Beaman et al. (2013)). However, considering the interplay between agriculture and climate change, before designing a policy focused on increasing the adoption of any technology, it is extremely relevant to understand the impacts of this technology on environmental outcomes.

The rest of the paper proceeds as follows. Section 2.2 presents background knowledge on double-cropping. Section 2.3 describes the different datasets used in our analysis. Section 2.4 presents our empirical strategy to evaluate the effect of longer periods continuously adopting the technology. Section 2.5 presents results and Section 2.6 robustness checks. Section 2.7 concludes by proposing policy implications of our findings and briefly discussing future paths for research.

2.2 Background - Double Cropping

In the 1970s, Brazil was a net importer of food commodities. Over the past five decades, however, the country passed through major transformations in the agriculture sector and has emerged as a global agricultural player, responsible for roughly 30% of the world's soybeans and 15% of its beef (FAOSTAT 2018). Mato Grosso, third largest state of Brazil, with an area of 90.3 million ha, was one of the states where this change was most pronounced: in fifty years, the annual grain production in the region increased from 1.7 to over 40 million tons (PAM-IBGE).

The initial agricultural model of the 1970s was based on intensive tillage, monoculture, and high inputs of fertilizers for controlling pests and diseases. As a result, soil erosion and nutrient exhaustion appeared and led to a decline in productivity (Polidoro et al. (2021))[1]. In the 90s, farm-

[1]Soil erosion affects soil health and productivity by removing the highly fertile topsoil and exposing the remaining soil (FAO (1998))

ers started to adopt new agriculture practices expecting to reverse the historically accelerated soil erosion and degradation (Kassam et al. (2019)). Farmers incorporated soil management techniques that today are encompassed as "conservation agriculture", whose key principles are minimum soil disturbance during planting, permanent soil cover with crop residues, and crop rotation (FAO (2021)).

Double-cropping started to be adopted by farmers, being a technology that incorporates all these three principles. First, the no-till concept, with the direct placement of the seeds under the residues of previous crops, allowed crops to grow without disturbing the soil with tillage use. Second, the overall land management system incorporated permanent soil cover. Finally, crop rotation, a planned sequence of crops growing in a regularly recurring succession on the same area of land. By revealed preference, we have evidence that farmers expect this technology to be more profitable than single-cropping. On our sample, 98% of the pixels had an experience with double-cropping at some point. During the study period, chose based on data availability, as explained in Section 2.3, double cropped area increased from 81% to 99% of the total soy-cultivated land in Mato Grosso.

The mechanism we explore as an explanation of double-cropping dynamic effects in productivity and fire resilience combine these three features of double cropping (no-tillage, soil cover and crop rotation) and can be summed up in its capacity to i) retain water in the soil and ii) increase fertility by improving nutrient cycling. Specifically, no-tillage reduces soil compaction and conserves soil moisture, allowing root penetration and increasing water exchange from the soil to the atmosphere. Soil cover improves soil structure and water penetration because adding organic matter increases soil aeration and the percentage of water-stable aggregates. Crop rotation affects soil microbiology and makes nutrients in the soil more available through nitrogen fixation. In sum, enhancement of soil structure, improvement on water infiltration and conservation, soil temperature balance and maintenance of soil organic matter characterize the mechanism we explore to explain increase in productivity and fire resilience combine these features of double cropping (Williams et al. (2018); Bank (2012); Lal (2003)).

In Mato Grosso, the use of double-crop systems involves soybeans in the first cycle and mainly maize or millet in the second cycle. For both crops, the plant cycle is usually of 120 days. With public investment, technology keeps advancing to facilitate the adoption of double-cropping. For instance, Embrapa (Brazilian agricultural research national center) has developed an adapted soybean seed that matures in only 110 days, thereby facilitating the cultivation of two crops in the same agricultural cycle.

The first harvest is usually planted in October-November, being harvested in January-February. The second crop sowing shortly follows the harvest of soy in order not to enter into its growing cycle when the dry season (winter, May-August) is harsher. Termination time of the first harvest may interfere with planting of the second crop.

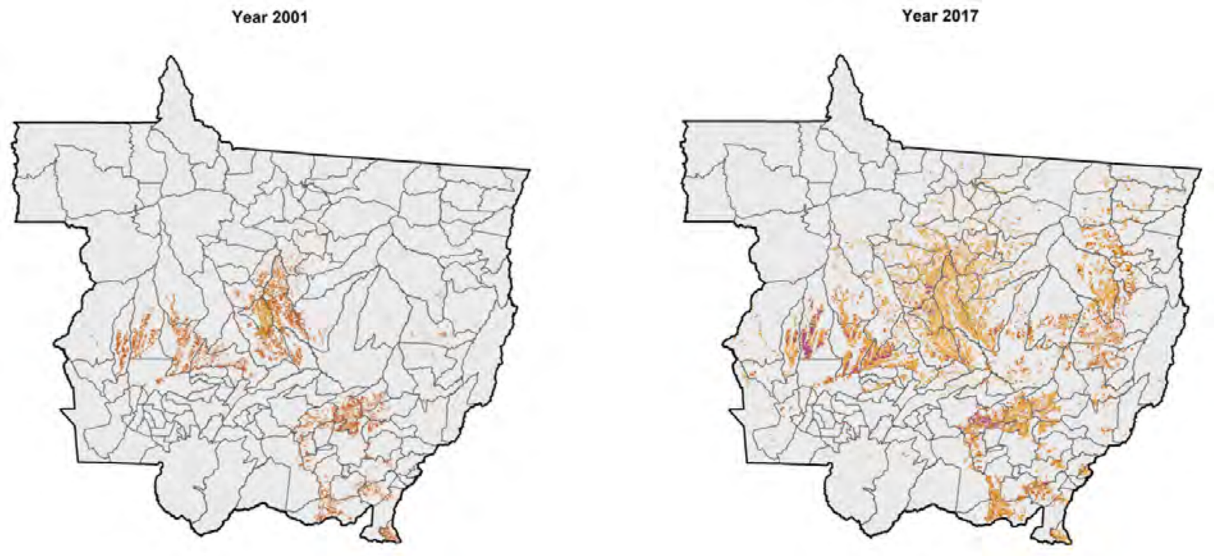
2.3 Data

Our analysis is done at the pixel level, using satellite data at 250-meter spatial resolution for Mato Grosso, spanning from 2001 until 2017. The advent of multiple satellite systems capable of capturing rich data from a broad spectrum (spatial and temporal) at the plot level have raised research possibilities and brought significant advances in measuring and understanding agricultural output in many different contexts.[2] Below we describe our double-cropping variable, the 4 outcome variables and controls we use.

1. Double-cropping. To create our measure of double-cropping, we use a dataset of yearly land use and land cover classification maps for Mato Grosso State, from 2001 to 2017, constructed by Simoes et al. (2020) and available at Câmara et al. (2019). Using innovative machine learning methods on satellite image time series provided by NASA from Moderate Resolution Imaging Spectroradiometer (MODIS), authors classify each pixel in one out of nine land cover classes: forest, cerrado, pasture, soybean - single crop, cotton - single crop, soybean-cotton (double crop), soybean-corn (double crop), soybean-millet (double crop), and soybean-sunflower (double crop). The satellite time series was coupled with 1,892 ground samples to train the algorithm. For pixels classified as double-cropping, user's accuracy was 90%. Figure 2.1 shows how the double-cropping spread over the state between 2001 and 2017.

[2]In agriculture, remote-sensed vegetation indices coupled with rainfall estimates are key inputs to track agricultural growing conditions and estimate crop output. For instance, short-term forecasts for food insecurity can directly inform food aid and other humanitarian resource allocation (Morss et al. (2008)). Forecasts are also used in a wide array of tasks, including in early government warning alerts and analysis of commercial trends (Fritz, 2019) . See Lobell et al. (2020) for a review.

Figure 2.1: **Double-cropping development between 2001-2017 in Mato Grosso.**



2. Productivity (NDVI - Normalized Difference Vegetation Index). For our outcome variables, we have 4 different outcomes. First, we use a vegetation index as an already validated proxy for agriculture productivity. Computed from simple ratios of reflectances at different wavelengths captured by satellite, the numerous vegetation indexes that exist are known to be related to vegetation health. Here we use the NDVI (Normalized Difference Vegetation Index), extract from MODIS/NASA (product MOD13Q1), which has commonly been used as a proxy for productivity (Lobell et al. (2019); Burke et al. (2021); Chivasa et al. (2017)). This variable has increasingly been used in Economics due to the facility of having productivity metrics without counting on collecting data on the ground through field surveys or on government estimates. [3] Farm-scale yield prediction is useful for a range of development applications, such as the targeting and evaluation of agricultural interventions and the rapid monitoring of rural livelihoods. We use the 95th percentile instead of the maximum to get rid of outliers and satellite measurement errors.

3. Soil Carbon (GPP - Gross Primary Production). To evaluate the mechanism of the dynamic effects of double cropping on the soil, we use the gross primary production (GPP) as a proxy for soil fertility. GPP measures the gross uptake of CO2 through plant photosynthesis, which is the main

[3]Indeed, satellite greenness metrics, measured as the growing season peak value of the green chlorophyll vegetation index, correlates much more strongly with real yields (using crop cut samples) than with self-reported by farmers. See Lobell et al. (2020).

driver of carbon sink in dryland,[4] accounting for the removal of over one quarter of the anthropogenic CO2 emissions each year (Spielmann et al. (2019)). GPP is the basis of vegetation growth and food production globally and plays a critical role in regulating atmospheric CO2 through its impact on ecosystem carbon balance (Imhoff et al. (2004); Xu et al. (2019)). Soil represents the most important storage of carbon on earth: soil carbon pool (2,500 Gt) is more than 3 times the size of the atmospheric pool (760 Gt) and about 4.5 times the size of the biotic (vegetation) pool (560 Gt) (Bank (2012)).

In contrast with forests, where carbon stocks is present 50% at the soil and 50% on vegetation (trees' stems and leaves), in cropland, carbon stocks are almost entirely (98%) stored at the soil (et al. Watson (2000); Ravindranath and Ostwald (2008)). Carbon from the atmosphere becomes soil carbon through the process of above-and below-ground decomposition of materials (related to cover crop feature of double-cropping) and release of sugars and amino acids, products from photosynthesis, from plant into the soil through the roots (related to crop rotation feature) (Austin et al. (2017); Lange et al. (2015)). We use GPP as a proxy for soil fertility as previous evidence shows that there are increases in grain productivity due to increase in soil organic carbon (Lal (2011, 2006), and that double-cropping promotes carbon sequestration in agricultural soils (Maia et al. (2022)).

Ideally, to properly evaluate soil carbon content researchers would do direct soil carbon assessment, which entails collecting soil samples in the field and doing lab analysis. As field sampling at the scale we aim to evaluate in this paper would be technically impossible, we use MODIS-derived GPP. Previous studies have shown that it is one of the most robust datasets to quantify the spatiotemporal variability of GPP at global scales (Chen et al. (2019)). In contrast with other dataset from MODIS that provide observations for every 8 or 16 days, GPP is only provided yearly, representing the sum of kg C/m².

4. Water availability (ET - Evapotranspiration). Water is one of the most important inputs in agriculture. In rainfed agriculture, water availability determines the start of the sowing period and affects the probability of crop failure. Evapotranspiration (ET) is a major component in the hydrologic cycle because it is the main channel for returning precipitation that falls annually over the global land back to the atmosphere. When water vapor leaves a vegetated surface, it is generally difficult to distinguish between

[4]Carbon is also sequestred by oceans. The efficiency of oceans and lands as carbon dioxide sinks has declined over time. These sinks currently remove an average of 55% of all anthropogenic carbon dioxide emissions (Global Carbon Project 2009).

transpiration from plants and evaporation from the soil surface. Therefore, these combined processes have been commonly named evapotranspiration.

ET is an important soil water balance component, playing a major role in determining the potential yields of cropland. Decreases in this important channel of the water cycle can lead to increased precipitation variability (Lee et al. (2012); Lee and Boyce (2010)), leaving farmers more exposed to climate risk. Moreover, less evapotranspiration during the dry season can delay the onset of the rainy season (Costa and Pires (2010); Spera et al. (2020)), shortening the stable wet season needed to do double-cropping. In a scenario of climate variability, estimating the amount of ET is becoming increasingly common among farmers, who are interested in having better estimates of the overall water budget in their systems. Information on ET at the farm level allows for planning of the agricultural cycle and efficient use of water resources, a useful tool during the dry season, when lack of precipitation usually limits plants' growth and yields.

Recent research shows that converting natural vegetation to agriculture substantially modifies evapotranspiration rates (Caballero et al. (2022); Silvério et al. (2015); Dias et al. (2015); Sampaio et al. (2007); Costa et al. (2007)). In general, evapotranspiration is lower in agricultural ecosystems compared with natural ecosystems. However, there is evidence that changes in rainfall regime after deforestation depend on the type of land cover that replaces the forest. For instance, compared to single-cropping, ET under double-cropping is higher, since it extends plants' growing season by 3- 4 months (Spera et al. (2016)).

A key factor to determine ET amounts in agriculture is the supply of water in cropland. Low water availability during plants' growing period may limit the crop development and reduce the evapotranspiration (FAO (1998)). When soil moisture is lacking, plants can present premature aging, resulting in leaf loss and decrease in transpiration of water. As plants grow, they develop roots downwards deep into the soil to draw water and nutrients up into their structure. As mentioned in Section 2, double-cropping has the capacity to retain water in the soil, thus diminishing the part of evaporation from the soil surface from ET (evaporation plus transpiration). However, as plants grow stronger, they can develop deeper roots, being able to access water located deeper in the soil (Kell (2011)).

We use ET as a proxy for the amount of water available for plants across the annual planting cycle. Scarcity of ground-based data led to the emergence of remote sensing methods to estimate ET, as satellite observations provide several of the land and atmospheric parameters needed for estimating ET[5]. Here, we make use of data provided by NASA MODIS (product MOD16A2) that provides estimates of 500-m 8-day accumulated values of ET , extending from 2001 to present. We re-project this data set to a 250m dataset and use the sum of observations to get total estimates of total mm/m3.

5. Climate resilience (Fire occurrence). Finally, we collect data on fire occurrence from Mapbiomas, which tracks whether a pixel presents evidence of vegetation burning. MapBiomas Fire project uses machine learning algorithms (deep learning) and provides annual maps of fire scars based on mosaics of images from the Landsat satellites with a spatial resolution of 30 meters [6].

In some cropping systems, burning is incorporated as a practice generally adopted by farmers. For instance, even though it represents a severe environmental and public health problem (Shindell et al. (2012)), the burning of stubble left in the ground after crop harvesting has become widely adopted in India to allow the use of mechanical harvesters (Behrer (2019)). However, considering the double-cropping technology, which implies using harvest leftovers as input for the next crop cycle (as soil cover), we assume fire occurrence to be undesirable from the perspective of farmers, and, thus, not intentionally initiated in their farm.

Natural fires are common in biome Cerrado as part of its ecological cycle. Especially during the wet season, natural small fires caused by lightning are part of some plants' growing cycle and also a natural tool to avoid the occurrence of bigger wildfires. However, Figure 2.9 in Appendix shows that most of the fire occurrence in our sample occurs during the months of May and December, concentrated in July-September, which represents the peak of the dry season. Even if the second crop has already been harvested by September, fire occurrences are undesirable for farmers as it decreases soil fertility (Pellegrini et al. (2018); Doerr and Santín (2016)).

Widespread fires are expected to become even more common if the frequency of extreme weather events increases (Brando et al. (2014); Baldocchi (2014); Alencar et al. (2015); Brando et al. (2020)). In a climate change scenario with higher temperature and higher frequency of droughts episodes, we analyze the effect of double-cropping adoption on fire at the pixel level as a proxy for climate resilience.

6. Controls.To increase the refinement of our analysis, we merge our

[5]ET depends on land surface characteristics such as the type of vegetation, soil moisture, available heat energy from sunlight, and atmospheric weather conditions.

[6]We re-projected that data to match our 250m resolution

double-cropping data with public data on farms' geographic location and officially registered boundaries at the Rural Environmental Registry of private properties (*Cadastro Ambiental Rural* (CAR) data, from Sparovek et al. (2019)). This allows us to identify in which farm each pixel we analyze is located, which will be essential to clean our estimation from the endogeneity coming from farmers' characteristics correlated to technology adoption and productivity. Figure 3.5 present the result of the combination of our detailed geo-located datasets.

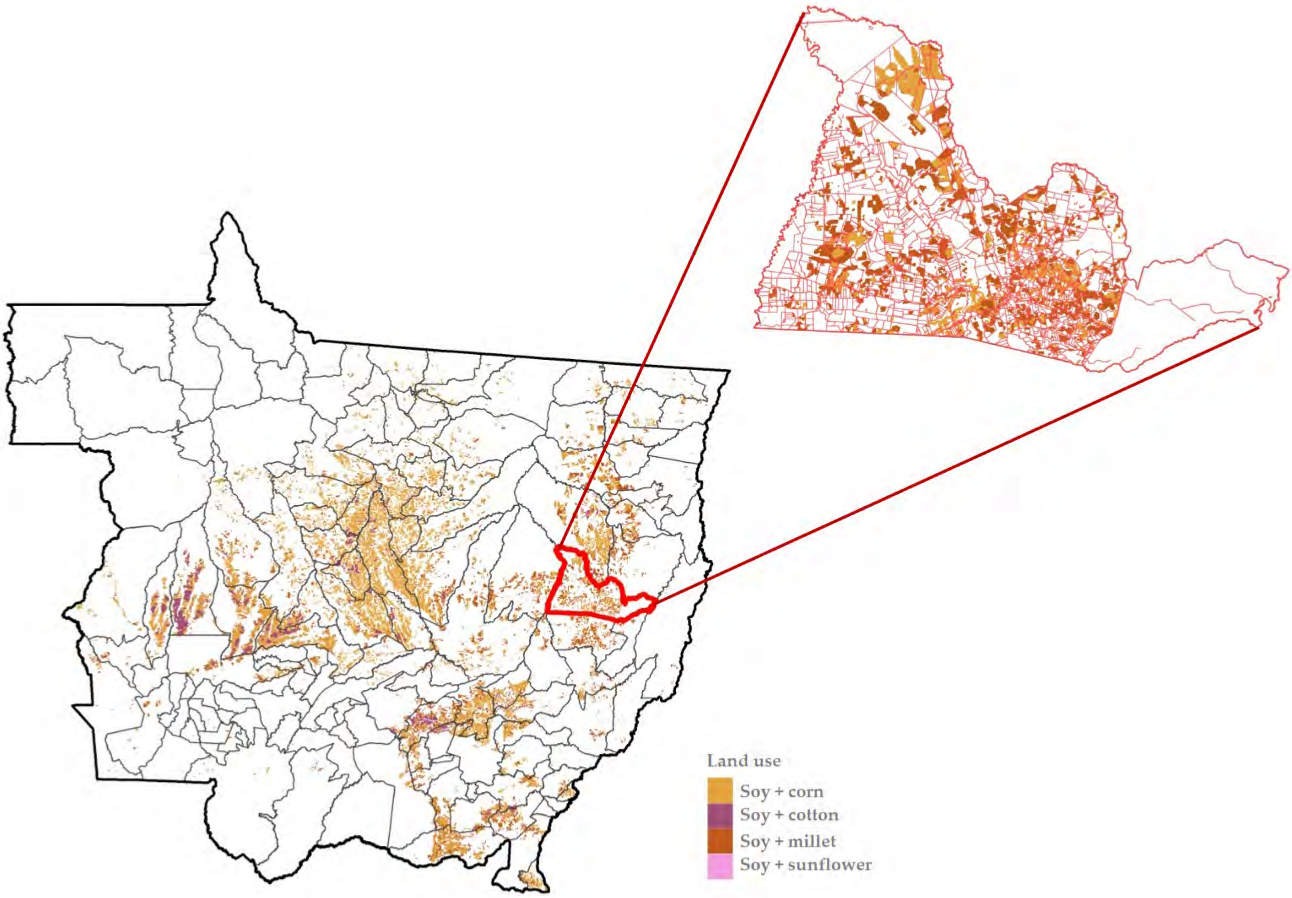


Figure 2.2: **Double-cropping and CAR data**

Note: Farms' limits in *Canarana - MT*.

Figure 2.3 presents the average of these variables across time. When possible, we broke them into first and second harvest - that is, from October to March for the first harvest, and from April till September for the second harvest. [7] Looking at the NDVI we see that there was a trend in productivity increase across all plots. We also notice that the second harvest seems to be more sensitive, with higher variance and some important breaks in years

[7] For GPP, this was not possible as NASA only provides annualized data. For fire, it did not make sense to break into as most of the fire occurrences happen in the second harvest time, as shown in Figure 2.3.

with extreme weather occurrences. In 2005, for example, there was a major drought that led to crop failure with losses of around 47%. That is consistent with the fact that the second crop cultivation is more constrained, as its beginning depends on the timing of the first one and its ends depends on weather, as the dry season starts in the middle of the growth period of the usual crops (maize and millet).

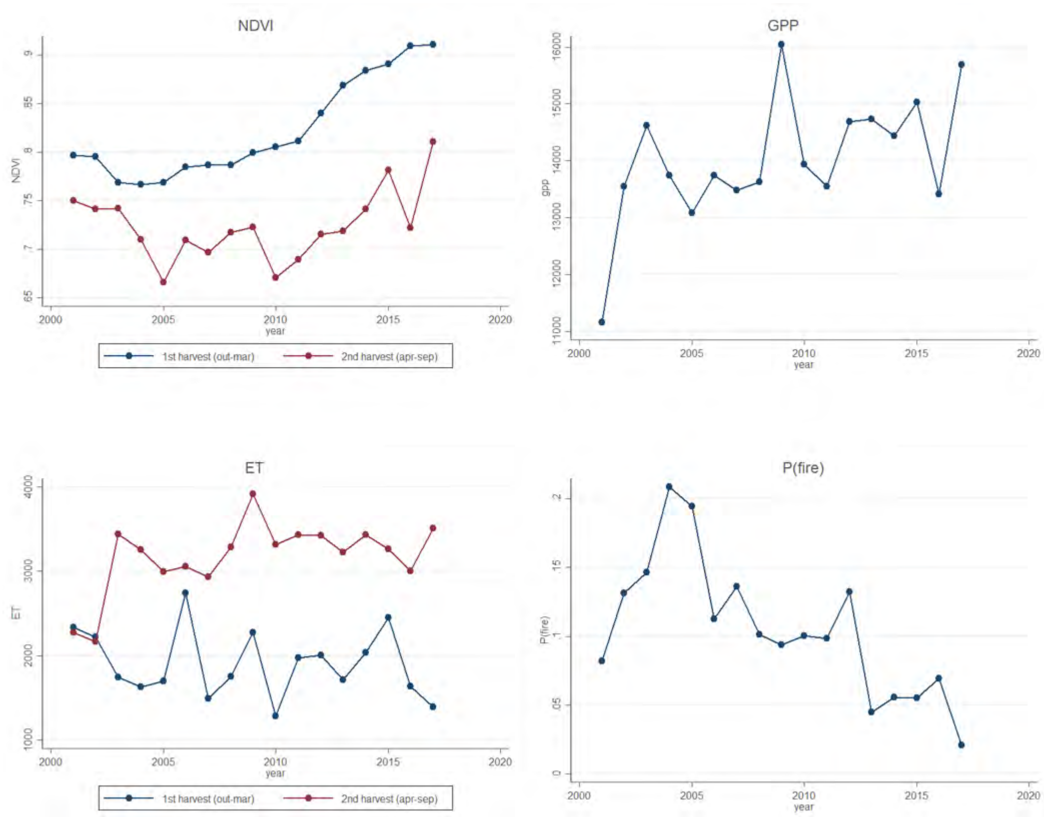


Figure 2.3: **Time series of the average of outcomes variables.**

Note: Average of outcome variables at the pixel level per year.

At the margin, the second harvest is more sensitive as it is more constrained on optimal planting time and it is also exposed to more challenging weather conditions. Being so, we see that when farmers invest in a technology that bring positive effects for the quality of the soil, the marginal dynamic effect from time exposure is bigger for the second harvest.

2.4 Empirical Strategy

Main specification. Technology is a choice in farmers' production function. Farmers' characteristics can be associated both with the decision to adopt a better technology and with the outcomes we will measure, such as productivity. To handle the endogeneity that is present on the decision to adopt the technology in the first place, we use the richness of a panel at the pixel-farm level. We run regressions at the pixel-year level and add two sets of fixed effects that bring robustness to our estimates. First, we add pixel fixed-effects, which cleans our results from the possibility that some plots have soil structures that are naturally more productive or adaptable than others to the technology we study.[8] Thus, any soil intrinsic fixed (or slow changing) characteristic can not be an explanation on the results we measure.

Second, we add double farm-year fixed-effects, ruling out any concern on more sophisticated farmers being the ones who decide to adopt a more innovative and with higher entry-costs technology. These fixed effects also safeguard our estimates from variation on weather, that would affect the productivity of crops especially in years with negative weather shocks. Since our estimation comes from comparing pixels within the farm, which will face the same weather, effects of weather variables will be captured by the farm-year fixed effect.

For our selected sample of pixels, described below, we estimate the following regression:

$$Outcome_{pft} = \alpha_p + \gamma_{ft} + \beta ADC_{pft} + \theta DC_{pft} + \varepsilon_{pft} \qquad (2\text{-}1)$$

where $Outcome_{pft}$ refers to one of the outcome variables of pixel p from farm f at year t; α_p controls for pixel fixed effects and γ_{ft} controls for farm-year fixed effects. ADC_{pft} refers to the accumulated years a pixel p stays under double cropping at each period t. Through this equation, instead of comparing units that use double-cropping with units that do not, we use the trajectory of the unit, thus comparing similar units that have been managed by the same farmer, but have a different trajectory as they started using double-cropping at different times.

We also add a dummy DC_{pft} for double-cropping at time t, captured by θ , which compares units that are both doing double-cropping, but are exposed differently to it. To account for spatial correlation, we clustered standard errors at the farm level. Variation across space displays significantly less "randomness," especially at smaller spatial scales (Auffhammer et al. (2013)), thus units managed by each farmer are probably correlated across time (in terms of weather shocks and farmers manager skills).

The coefficient of interest, β, refers to estimates of the effect of higher time exposure to treatment on our outcomes. One concern in this specifica-

[8]Few factors delimit the physico-chemical maximum limit to storage of carbon in the soil, such as texture, mineralogy, depth, bulk density and aeration.

tion is that farmers might be learning along the time how to better implement the treatment. This would lead to plots having better results over time due to farmers' learning process and subsequent improvements on the use of the technology. An assumption behind our specification is that farmers will transport the knowledge he acquired in the first cohorts into the next plots he starts to treat. That is, the results found here can not be explained by pure learning – pixels longer in treatment would perform better because farmers are learning as time goes by.

First vs. Second harvest. In this analysis, it is relevant to separate the first harvest (soy) from the second (maize or millet) as they present different restrictions on farmers' production function. The first one is usually the preferred crop and the main focus of farmers' production. The second harvest comes as a surplus on the agricultural cycle as it is usually more exposed to climate shocks – it occurs closer to the dry season. Moreover, the second cycle is time-restricted on the performance of the first crop: if the rainy season is delayed for the beginning of the first cycle, the second crop will have a shorter window to grow before the dry season comes. In rainfed agriculture, the rainy season determines the start of the sowing period and affects the probability of crop failure.

When data was available, we created separate variables for the two crops, estimating equation 2-1 above separately for the first harvest and the second one. For instance, in the analysis of productivity (NDVI) and water availability (ET) we estimate the effects of double cropping for different harvests. We can not do it for carbon uptake (GPP) – due to data availability – and fire occurrence – due to concentration of fire occurrence in the dry season (second harvest).

Sample selection. Our dataset faces two important restrictions. First, it is truncated, due to data availability to previous years. Our panel on double-cropping adoption starts in 2001, however, double-cropping started to be widely adopted in Mato Grosso in the 1990s. Figure 2.10 in Appendix shows we have a left-side truncated database: from departure, 20% of all pixels doing agriculture were already incorporating double-cropping technology. Second, and related to the issue of self-selection in technology adoption, we have a discontinuity on treatment that we can not control for. Pixels switching on and off on treatment status makes unclear how to interpret the coefficients of our main regressor, which is years accumulated in double-cropping. Biological dynamics happening at the soil are complex and probably not linear, which make it unclear how soil would react to stops on treatment after some consecutive years on it.

To overcome that, we decide to look at plots that were absorbed into the technology, that is, plots that once started using double-cropping, they never stopped it. With a total of 275,533 pixels, these sample represents 13.2% of total pool of pixels that adopted double-cropping at least once in our panel. To measure the dynamic effect of the technology on the soil, we look at plots that started double-cropping in 2006 onwards. This allows us to ensure that for at least 5 years, those plots were not treated and the effect we measure is not coming from previous use of the technology on the plot. For robustness, we present in Section 6 results of our main specifications for two different groups 1) those that were switching on-and-off on treatment status and 2) pixels that did double-cropping continuously but stopped sometime before our end-year. With the exception of the effect on soil absorption (GPP), coefficients remain significant and in the same direction as our selected sample, even though with considerably smaller coefficients.

To handle concerns related to these selected sample, table 2.1 presents a comparison of baseline characteristics for units that started double-cropping at different years. To test whether farmers might have selected the best plots to start using the technology, we run a regression, adding farm fixed effects, of the average of our measured outcome variables at baseline (between 2001-2005) on dummies for whether that plot was in the first cohort, second cohort, third, fourth, fifth, sixth, or more. Our main concern is that different time exposure to double cropping, which is the variation we exploit in our specification, would be related to plot-selection within-farm, with longer periods in double-cropping correlated to selection of better plots in the first cohort of treated plots within-farm. Results in table 2.1 points that, if anything, plots that entered later on the treatment are better off than the first plot in terms of soil fertility (GPP) and water availability (ET) during the baseline, ensuring that the results presented in the next section can not be explained by first plots being more better off at baseline.

Table 2.2 presents the descriptive statistics for our selected sample of pixels. On average, farms have 1590 hectares, which put them at the 90th percentile among farms in Mato Grosso in terms of total area. We estimate our results on a panel composed of 275,533 pixels from 9,725 farms. On average, farmers present 2.19 different cohorts of plots starting double-cropping at different years within their farm. In terms of treatment intensity, by the end of the time studied here, on average, plots have been doing for 4.5 years, adopting the technology in 50.7% of the total area of their land. We added an extra column with the same averages for the whole set of pixels

Table 2.1: **Pixels' baseline characteristics**

	NDVI		ET		GPP	P(fire)
	1st harvest	2nd haverst	1st harvest	2nd haverst		
	(1)	(2)	(3)	(4)	(5)	(6)
2nd cohort	-5.166***	18.14***	4.907***	18.48***	39.62***	0.000461
	(1.312)	(1.853)	(0.699)	(1.713)	(5.070)	(0.000476)
3rd cohort	-6.507***	38.49***	10.94***	38.86***	91.23***	-5.63e-05
	(2.086)	(2.583)	(1.090)	(2.266)	(6.071)	(0.000700)
4th cohort	-9.759***	57.00***	16.63***	61.08***	143.8***	-0.000969
	(3.132)	(4.259)	(1.565)	(4.698)	(13.46)	(0.00104)
5th cohort	-14.21***	71.39***	23.35***	82.21***	193.2***	-0.000885
	(3.977)	(6.037)	(2.316)	(7.167)	(21.79)	(0.00230)
>6th cohort	-16.52**	93.28***	26.01***	105.2***	246.9***	-0.00107
	(7.073)	(8.952)	(3.632)	(7.487)	(21.09)	(0.00290)
Constant	596.2***	485.3***	122.2***	202.2***	940.8***	0.0151***
	(1.156)	(1.540)	(0.579)	(1.434)	(3.753)	(0.000407)
Observations	273,892	273,892	273,868	273,868	273,868	273,892
Farm fixed-effect	Y	Y	Y	Y	Y	Y
Adjusted R-squared	0.539	0.625	0.620	0.720	0.757	0.501

Notes: This table reports the mean of our main outcome variables on baseline (2001-2005), comparing different cohorts within-farm. Observation unit is pixel p from farm f. Each column presents the result of an OLS regression with farm fixed-effects in each the dependent variable appears on top of the column. Standard errors are clustered by farm and displayed in brackets.

that experienced double-cropping at least once in the time period of our panel, from which we see that our sample is composed with lager farms and with less experience with double-cropping.

2.5 Results

This Section presents the results of our estimations. First, we show that longer periods continuously adopting double-cropping result in productivity gains. To understand the mechanism behind this, we show how the technology is related to increases in the amount of carbon stored in the soil, and how that reflects improvements on soils' water holding capacity. This increase in water retention explains the final result we present in terms of fire resilience.

2.5.1 Productivity

First, Table 2.3 presents the results from our estimation of the dynamic effect of technology adoption on productivity. Columns (1) - (2) show the accumulated effect of doing double cropping at that pixel during the first harvest (soy cycle). Controlling for farmers' characteristics using farm $\times$ year

Table 2.2: **Summary Statistics**

	Selected sample					Other pixels doing double-cropping		
	N	mean	sd	min	max	N	mean	sd
Farm characteristics								
Area total CAR	9,725	1,589	4,307	2.97	158,040	30,421	1,169	3,396
% area double cropping (endline)	9,725	.507	.294	0	1	30,419	.288	.355
# treatment groups by farm	9,725	2.19	1.50	1	11			
Pixel characteristics								
Years in double cropping (endline)	275,533	4.57	2.88	1	11	1,760,888	7.80	5.45
Outcome variables (baseline)								
Veg index (1st harvest)	275,533	78.15	10.39	20.92	99.97	1,760,888	83.19	10.01
Veg index (2nd harvest)	275,533	73.56	12.35	13.34	99.94	1,760,888	67.9	15.06
Gross Primary Production	275,509	13,267	4,827	2840	29602	1,760,888	10,463	3,517
Evapotrans. (1st harvest)	273,312	1,981	911	4	7311	1,760,888	1.681	790
Evapotrans. (2nd harvest)	275,496	2,782	1582	8	9610	1,760,888	1783	1.287
Dummy fire	275,533	.142	.349	0	1	1,760,888	.071	.257

Notes: Data on double-cropping from Camara et al (2019). NDVI, GPP and ET from MODIS-NASA. Fire from Mapbiomas. Farm data was computed using information farms' officially registered boundaries at the Rural Environmental Registry of private properties (Cadastro Ambiental Rural (CAR) data, from Sparoveka et al (2019).

fixed effects presents a positive coefficient (column 1). However, its magnitude is small. One additional year of double cropping increases NDVI in the first harvest by 0.13% relative to the average (0.0985/78.15 = 0.0013). This finding is considerably different when we focus on the second harvest. Column (3) show that the effect is considerably higher. On average, each additional year doing double-cropping increases productivity by 3.89% during the second harvest. This implies that pixels that adopt double cropping for one decade have productivity gains about 40% larger than pixels that just started. This is a large effect, comparable to the mean return to fertilizer use estimated in other settings (Duflo et al. (2008); Suri (2011)).

These results show that plots exposed to double-cropping for longer periods present better productivity. One remaining concern is that an alternative explanation is that farmers selected the best plots to start using the technology, meaning that the longer exposure to double cropping would present best results due to plot-selection within-farm for the first treated plots. To account for that, columns (2) and (4) include baseline characteristics of the dependent variable as a linear trend. We include the average of NDVI between 2000-2005 interacted with the year variable, to take into account pre-trends of each pixel at baseline, cleaning our results of accumulated years in double-cropping from pixel selection at baseline.

We see that the results sustain after taking into account the selection that could happen within-farm. Column (4) show productivity gains of 3.21% for each additional year in double-cropping. Taken together, the

Table 2.3: **Effect of accumulated years in DC on vegetation health index**

	1st harvest		2nd harvest	
Dep. var: NDVI	(1)	(2)	(3)	(4)
Accum. double cropping	0.0985**	0.232***	2.864***	2.367***
	(0.0426)	(0.0350)	(0.106)	(0.0926)
Dummy double cropping	4.979***	4.877***	6.502***	6.171***
	(0.148)	(0.147)	(0.253)	(0.238)
Constant	80.45***	74.12***	67.38***	61.43***
	(0.0662)	(0.684)	(0.145)	(0.706)
Observations	4,656,164	4,656,164	4,656,164	4,656,164
Adjusted R-squared	0.715	0.744	0.688	0.711
Number of periods	17 years	17 years	17 years	17 years
Number of farms	9725	9725	9725	9725
Number of pixels	275533	275533	275533	275533
Pixel FE	X	X	X	X
Farm-year FE	X	X	X	X
Baseline trend		X		X
Mean Dep. Var. baseline	78.15	78.15	73.56	73.56

Notes: This table reports the effects of the accumulated years doing double-cropping on NDVI. Observation unit is NDVI of pixel p at farm f in year t, where t refers to 17 years (2001-2017). Each column presents the result of an OLS regression with pixel and farm-year fixed-effects. Standard errors are clustered by farm and displayed in brackets.

results from Table 2.3 are consistent with the idea that adopting double continuously increases productivity. The effects are much larger for second harvest productivity than for first harvest productivity. This is consistent with second harvest being much more sensitive to shocks, in general, and to improvements in soil properties, in particular. This is largely due to the fact that farmers have much more flexibility to mitigate shocks (by adjusting planting and harvest dates and input use) in the first than in the second harvest.

One final discussion on the differences between results in the first vs. second cycle is related to a crop-specific property that would account for these differences. Considering that the mechanisms discussed above related to soil improvement (carbon uptake and water availability), we expect all crops considered here (soy, maize and millet) to benefit from improvements in the soil. That is, if data were available with variation on the type of crops used in the first vs. second cycle, we do not expect for a crop-specific fixed effect to change our results. We interpret the different results across harvests as farmers having less degrees of freedom to mitigate shocks in the second harvest. Adjusting sowing and focusing input use in the first cycle seems to be the reason why marginal improvements in the soil does not majorly affect productivity in first cycle.

The results discussed above constrains the effect of accumulated years of double cropping on NDVI to be linear. However, it is possible the effects changes over time. To analyze this, we replace the linear variable on accumulated years of double cropping by dummies of years of exposure to double cropping to estimate the effects non-parametrically. Figure 2.4 plots the coefficients for different categorical dummies of the number of years accumulated in double-cropping adoption at each pixel-year observation. We focus on the specifications with farm × year fixed effects and baseline trend (columns (2) and (4)). For the first harvest (blue circles), the figure indicates doing double cropping does not increases productivity substantially for all levels of exposure. However, for the second harvest (red diamonds), the use of the double cropping consistently increases on the amount of years using the technology. The effects are almost linear although we observe a small levelling for longer exposures. Comparing units that experienced 3 years of double-cropping with those that experienced 8 years, we estimate an increase of 80% on productivity of the second crop for the units longer in double-cropping.

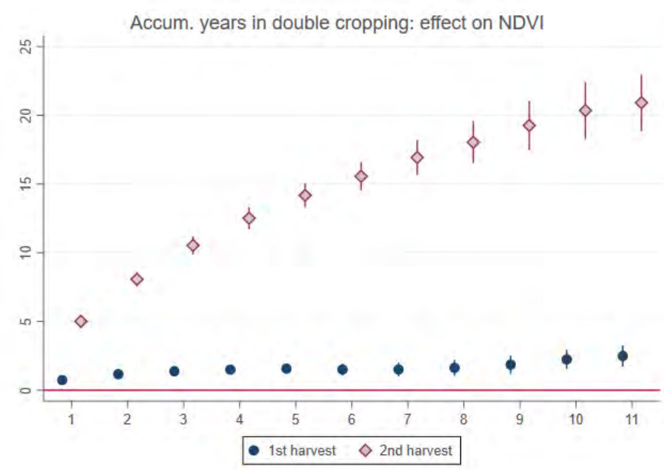


Figure 2.4: **Coefficients for categorical dummies from ADC_{pft} on NDVI.**

Note: Including pixel and farm-year fixed effects, and controlling for pixel's baseline characteristic. Standard errors clustered at farm level.

2.5.2 Mechanisms

To understand the mechanisms leading to the productivity gains documented in Table 2.3, we explore detailed data on soil properties to test whether longer exposure to double cropping influences it. We focus on two properties: soil fertility and water availability. We begin examining the effects of exposure to double cropping on soil fertility. Soil fertility is an immediate consequence of the amount of soil organic matter (and hence carbon) a soil contains (Lal (2011); Gough (2011); van Groenigen et al. (2017)). We proxy it using GPP, a measure of the amount of carbon stored in the soil. Table 2.4 reports the results.[9]

Column 1 indicates that accumulated years of double cropping significantly increase GPP. In our preferred specification that take into account baseline characteristics (colum (2)), the estimates suggest one additional year adopting the double cropping generates a 1.4% increase in GPP. To evaluate whether the effect of exposure to double cropping is linear, Figure 2.5 plots exposure-specific coefficients of double cropping on GPP. Similar to what we found for productivity, we see the effects of exposure to double cropping increase almost linearly over time.

Table 2.4: **Effect of accumulated years in DC on carbon uptake**

Dep. var.: GPP	(1)	(2)
Accum. double cropping	276.5***	191.8***
	(20.02)	(13.23)
Dummy double cropping	745.5***	725.1***
	(40.62)	(36.93)
Constant	13,514***	11,422***
	(29.12)	(177.2)
Observations	4,655,756	4,655,756
Adjusted R-squared	0.911	0.916
Number of periods	17 years	17 years
Number of farms	9,725	9,725
Number of pixels	275,533	275,533
Pixel FE	X	X
Farm-year FE	X	X
Baseline trend		X
Mean Dep. Var. baseline	13,981	13,981

Notes: This table reports the effects of the accumulated years doing double-cropping on GPP. Observation unit is GPP of pixel p at farm f in year t, where t refers to 17 years (2001-2017). Each column presents the result of an OLS regression with pixel and year or farm-year fixed-effects. Standard errors are clustered by farm and displayed in brackets.

[9] As explained in Section 2.3, it is not possible to break GPP into first and second harvest as this information is only available yearly.

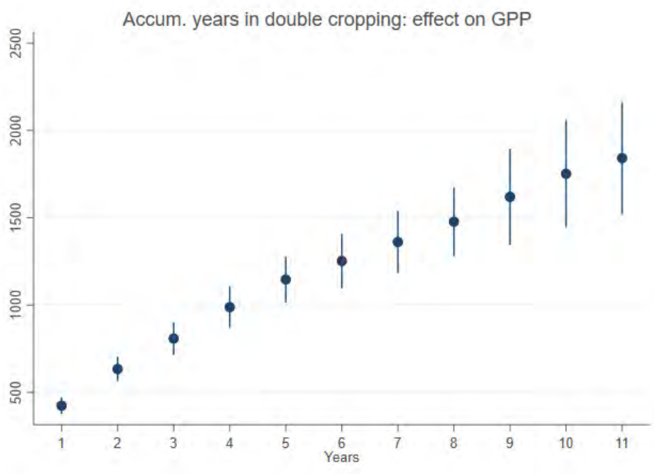


Figure 2.5: **Coefficients for categorical dummies from ADC_{pft} on GPP.**

Note: Including pixel and farm-year fixed effects, and controlling for pixel's baseline characteristic. Standard errors clustered at farm level.

We then turn attention to water availability. By increasing organic matter in the soil, double cropping might improve physical properties such as water infiltration and water holding capacity (Paustian et al. (2016); Smith et al. (2008)). We use data on evapotranspiration (ET), a measure of the amount of water is released through water evaporation or plant transpiration, to examine whether exposure to double cropping affects water availability. Table 2.5 reports the results.

Columns (1) - (2) report that accumulated years of double cropping increase ET during the first harvest.Quantitatively, in our preferred specification, we find each additional year of double cropping increases ET by a 1.6% in the first harvest. Columns (3) - (4) document the effects of accumulated years of double cropping on ET are much larger during the second harvest. Our estimates indicates that each additional year generates an increase of 3.4% in ET ($\approx$ 95mm).

Figure 2.6 provides graphical evidence of the resuls presented in Table 2.5. The effects of exposure to double cropping during the first harvest are basically zero up to five years of exposure, becoming positive after. The effects of exposure to double cropping on the second harvest, on the other hand, are roughly linear.

Overall, these results are consistent with earlier evidence that the adoption of double cropping can minimize the impacts of land-use conversion from forest to cropland on the hydrologic cycle (Spera et al., 2016). The increase in ET can be explained by several mechanisms: it might increase leaf area and root depth. Increases in leaf area increase transpiration while deeper roots mean plants acquire water at higher soil depth, enabling more continuous access to deep water. This last mechanism might explain higher transpiration even throughout the dry season in Cerrado (Costa and Pires (2010); Oliveira et al. (2005); Garcia-Montiel et al. (2008)).

Table 2.5: **Effect of accumulated years in DC on ET**

	1st harvest		2nd harvest	
Dep. var.: Evapotranspiration	(1)	(2)	(3)	(4)
Accum. double cropping	36.57***	32.56***	143.2***	94.85***
	(4.599)	(4.558)	(9.508)	(6.542)
Dummy double cropping	-74.21***	-81.79***	153.7***	147.3***
	(10.63)	(10.41)	(16.32)	(15.46)
Constant	1,892***	1,634***	2,981***	2,446***
	(7.008)	(22.75)	(11.91)	(49.04)
Observations	4,631,156	4,631,156	4,655,536	4,655,536
Adjusted R-squared	0.710	0.719	0.830	0.841
Number of periods	17 years	17 years	17 years	17 years
Number of farms	9,725	9,725	9,725	9,725
Number of pixels	275,533	275,533	275,533	275,533
Pixel FE	X	X	X	X
Farm-year FE	X	X	X	X
Baseline trend		X		X
Mean Dep. Var. baseline	1980.1	1980.1	2782.1	2782.1

Notes: This table reports the effects of the accumulated years doing double-cropping on ET. Observation unit is NDVI of pixel p at farm f in year t, where t refers to 17 years (2001-2017). Each column presents the result of an OLS regression with pixel and year or farm-year fixed-effects. Standard errors are clustered by farm and displayed in brackets.

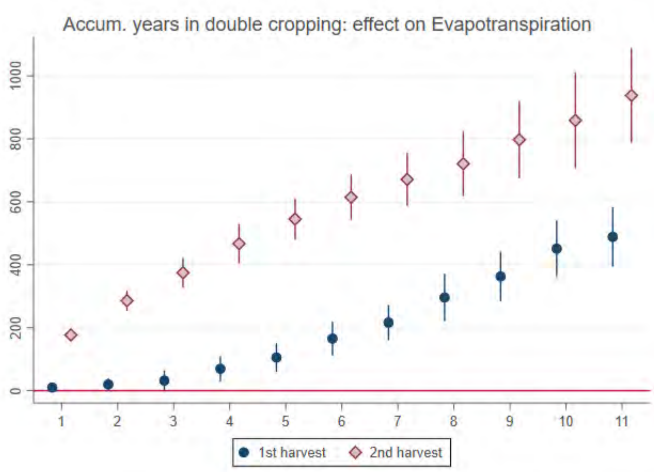


Figure 2.6: **Coefficients for categorical dummies from ADC_{pft} on ET.**

Note: Including pixel and farm-year fixed effects, and controlling for pixel's baseline characteristic. Standard errors clustered at farm level.

2.5.3 Climate resilience: fire occurrence

Finally, we estimate the effect of higher exposure to double-cropping on the probability of fire occurrence at the pixel-level. Besides spark and fuel, fire occurrence depends on the quality of the flammable fuel. Crops themselves and cover crops are natural fuels. However, their flammability will depend on the amount of water available at the system. The more dry the soil and crops are, the easier it will be for fire to carry at cropland . As cover cropping decreases direct sunlight at soil, preserving soil moisture, and soil carbon increases water retention capacity, we expect double-cropping to prevent burning in plots that have been doing it for longer.

Table 2.6 shows that, conditional on adopting double-cropping at some point, each additional year doing it decreases the probability of fire occurrence at the pixel level - even though the size of this effect is considerably lower when we add the farm-pixel fixed effect. Finally, breaking the analysis across time non-parametrically, Figure2.7 confirms that the effect is decreasing. The coefficient on Column (2) might be low as the first years on double-cropping do not have a significant effect on diminishing the probability of fire occurrence. This is consistent with the fact that some biological process at the soil takes more time than the usual 1-year period of the agricultural cycle. Indeed, from carbon uptake by plants through photosynthesis until forming soil organic carbon in its more stable form can take over 4 years (FAO (2021)).

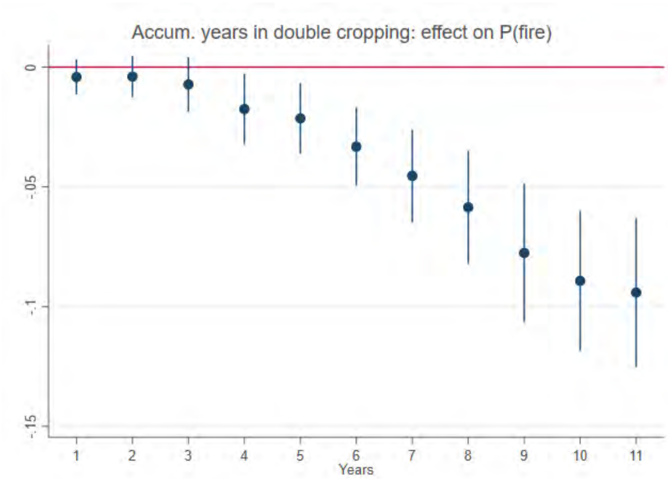


Figure 2.7: **Coefficients for categorical dummies from ADC_{pft} on fire.**

Note: Including pixel and farm-year fixed effects, and controlling for pixel's baseline characteristic. Standard errors clustered at farm level.

Under the assumption that farmers would implement fire prevention

Table 2.6: **Effect of accumulated years in DC on fire occurrences**

Dep. var.: Dummy fire	(1)	(2)
Accum. double cropping	-0.00693***	-0.00661***
	(0.00171)	(0.00143)
Dummy double cropping	-0.0118***	-0.0108***
	(0.00409)	(0.00384)
Constant	0.116***	0.0978***
	(0.00244)	(0.00270)
Observations	4,656,164	4,656,164
Adjusted R-squared	0.454	0.500
Number of periods	17 years	17 years
Number of farms	9,725	9,725
Number of pixels	275,533	275,533
Pixel FE	X	X
Farm-year FE	X	X
Baseline trend		X
Mean Dep. Var. baseline	.141	.141

Notes: This table reports the effects of the accumulated years doing double-cropping on Fire. Observation unit is Fire occurrence in pixel p at farm f in year t, where t refers to 17 years (2001-2017). Each column presents the result of an OLS regression with pixel and year or farm-year fixed-effects. Standard errors are clustered by farm and displayed in brackets.

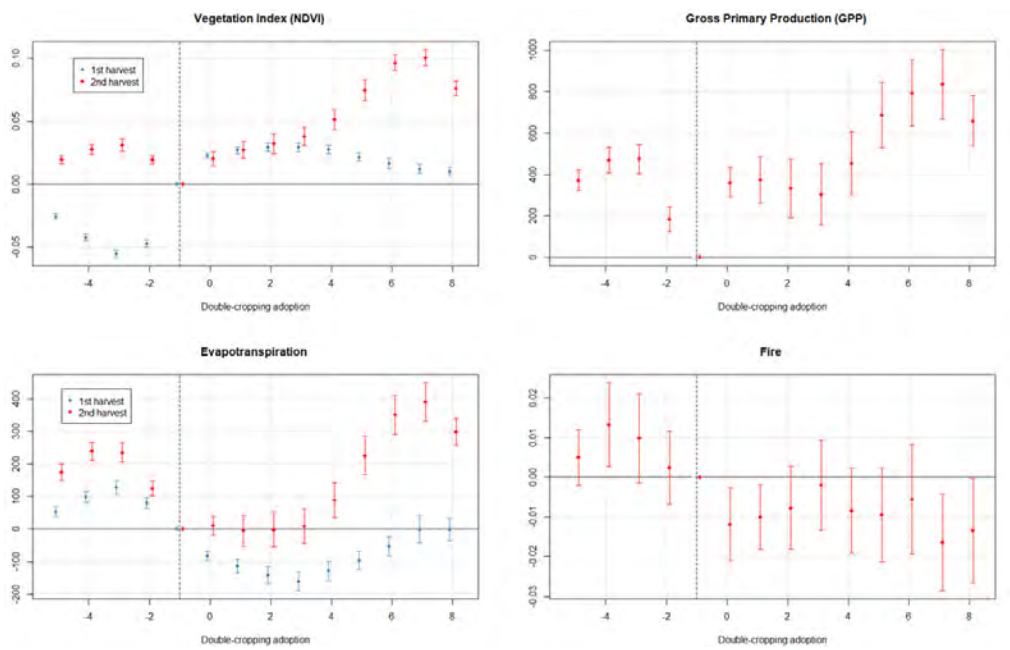
techniques in all plots similarly, not favoring plots that started double-cropping earlier, we estimate that for the median pixel in terms of double-cropping exposure at endline (4.6 years), there is a decrease of 14.8% on fire probability due to the use of technology when compared to baseline fire estimates.

2.6 Robustness

1. Event Study. The focus of this research is not on understanding the decision to use or not the double-cropping technology (extensive margin), but actually on the intensive margin: what happens over time after the longer a plot adopted double-cropping. To complement the evidence presented before, we make use of a staggered diff-in-differences approach to study the dynamics effect of double-cropping in the long-run. We use Sun and Abraham (2021) approach and present the results in Figure 2.8. As reference periods, beside t=-1, we aggregate all periods prior to 5 years before treatment and 8 years onwards after treatment at the coefficients in the tails. Even though the figures present pre-trends for all variables, recent literature shows that causal inference is valid even when endogeneity leads to pre-event trends in the outcome (Freyaldenhoven et al. (2019)).

For NDVI and ET we break the analysis into first and second crops. We see that our key results sustain. After the adoption of double-cropping, there are increasing gains in productivity during the second harvest, carbon accumulation, more water availability and diminishing probability of fire occurrence. For all variables we see a break in the trend before and after technology adoption. However, differently from results in Figures 2.4 to 2.7, these Figures show that the dynamic positive effects of double-cropping adoption take 4-5 years to peak, which is consistent with previous evidence that carbon soil accumulation can take time to happen. We also see that GPP tends to stabilize after 5 years, and the effect on fire seems to be relevant only after 7 years on double-cropping.

Figure 2.8: **Event-study estimation.**



2. Testing other samples. One of the reasons to select a sample of pixels that were absorbed into treatment is the challenge that comes in estimating the effect of higher exposure to treatment in units that interrupted treatment in the middle. They might have interrupted once and never come back, or they might interrupt and come back after some periods out. Because we do not have the detailed chemical-biological knowledge to estimate how dynamics of the soil would react to discontinuities on double-cropping adoption, we decided to focus our analysis on units that are continuously treated. However, in this Section we present the results from our specifications in two different samples.

First, we present the effect of higher exposure to double cropping for pixels that were switching on-and-off into treatment in our panel. Table 2.7

shows us that even though most of the coefficients keep the signal and significance, the size of the coefficient decreases considerably. GPP is the only coefficient that changes sign, but the coefficient now is 10% the size from the estimate in our preferred sample.

Table 2.7: **Testing other sample: pixels switching on and off**

	NDVI		ET		GPP	P(fire)
	1st harvest	2nd haverst	1st harvest	2nd haverst		
	(1)	(2)	(3)	(4)	(5)	(6)
Accum. double cropping	-0.00211***	0.0128***	5.768***	6.189***	-27.83***	-0.000821***
	(0.000140)	(0.000334)	(1.025)	(2.129)	(3.481)	(0.000277)
Dummy double cropping	0.0145***	0.0346***	-14.07***	58.63***	202.2***	-0.00390***
	(0.000361)	(0.00111)	(1.753)	(3.421)	(7.788)	(0.000605)
Observations	20,468,816	20,468,816	20,428,857	20,459,860	20,460,095	20,468,816
Adjusted R-squared	0.653	0.660	0.680	0.865	0.911	0.397
Number of periods	17 years	17 years	17 years	17 years	17 years	17 years
Number of farms	23226	23226	23226	23226	23226	23226
Number of pixels	1205994	1205994	1205994	1205994	1205994	1205994
Pixel FE	Y	Y	Y	Y	Y	Y
Farm-year FE	Y	Y	Y	Y	Y	Y
Mean Dep. Var. (baseline)	.8710	.6424	1710.9	1736.2	10533.7	.049

Notes: This table reports the effects of the accumulated years doing double-cropping on different outcome variables for the sample of pixels that were intermittently implementing double-cropping. Observation unit is pixel p at farm f in year t, where t refers to 17 years (2001-2017). Each column presents the result of an OLS regression with farm fixed-effects in each the dependent variable appears on top of the column. Standard errors are clustered by farm and displayed in brackets.

Second, we test our specification in a sample of pixels that give up treatment in the middle of our panel. That is, they started and stayed continuously for a period, but stopped at some time before 2017. In Table 2.8 we see again that, with exception of GPP, the signal and significance are sustained. In both this sample and the selected one, we need to make a discretionary decision on how to construct the variable of accumulated years in double cropping. For instance, based on the findings of positive dynamic effects of double-cropping in our preferred sample, we assume that once out of treatment, the benefit of the treatment sustains for the following years.

2.7 Conclusion

The design of effective climate policies in Brazil needs to encompass one sector that has a direct and important connection with the environment: agriculture. On one hand, agriculture is one of the main sources responsible for greenhouse gas emissions in Brazil, accounting directly for 20% of

Table 2.8: **Testing other sample: pixels that started double-cropping and stopped**

	NDVI		ET		GPP	P(fire)
	1st harvest	2nd haverst	1st harvest	2nd haverst		
	(1)	(2)	(3)	(4)	(5)	(6)
Accum. double cropping	-0.00151***	0.0115***	9.747***	16.53***	16.79	-0.00286***
	(0.000290)	(0.000582)	(2.305)	(5.161)	(10.83)	(0.000612)
Dummy double cropping	0.0379***	0.0167***	-78.26***	-43.51***	146.7***	-0.00617***
	(0.00161)	(0.00227)	(6.761)	(12.77)	(25.00)	(0.00224)
Observations	1,861,687	1,861,687	1,857,317	1,861,387	1,861,415	1,861,687
Adjusted R-squared	0.715	0.727	0.744	0.882	0.940	0.478
Number of periods	17 years	17 years	17 years	17 years	17 years	17 years
Number of farms	10005	10005	10005	10005	10005	10005
Number of pixels	112272	112272	112272	112272	112272	112272
Pixel FE	Y	Y	Y	Y	Y	Y
Farm-year FE	Y	Y	Y	Y	Y	Y
Mean Dep. Var. (baseline)	.8725	.6739	1901.9	2716.2	12994.9	.050

Notes: This table reports the effects of the accumulated years doing double-cropping on different outcome variables for the sample of pixels that were continuously implementing double-cropping but that stopped before endline (2017). Observation unit is pixel p at farm f in year t, where t refers to 17 years (2001-2017). Each column presents the result of an OLS regression with farm fixed-effects in each the dependent variable appears on top of the column. Standard errors are clustered by farm and displayed in brackets..

total emissions.[10] On the other hand, the sector presents the uniqueness of contributing positively to the global carbon budget as its fundamental input of productivity, plants' growth through photosynthesis, removes CO2 from the atmosphere. As both food security and climate change become more pressing issues globally, it is important to converge the dual-role that agriculture presents by finding technologies that increase productivity, enhance resilience to climate change, and reduce the GHG emissions.

In this paper, we document dynamic effects associated to agricultural practices in the state of Mato Grosso (Brazil) – an agricultural hub of global importance. Specifically, we use within-farm variation on the timing of adoption of double cropping to examine it dynamic effects on soil quality, climate resilience, and, ultimately, long-term productivity.

Our analysis explores rich satellite-based information on technology use, productivity soil properties, and fire incidence. First, we document that the length of exposure to double cropping increases productivity. Second, we tie this increase in productivity to changes in soil properties: longer exposures to double cropping increase soil's ability to store carbon and water. Third, we document that these changes in soil properties lead to lower fire incidence.

[10]Data from SEEG 2020.

Our results have immediate consequences for public policies. Reconciling food production and climate change mitigation requires identifying technologies that simultaneously increase productivity, carbon sequestration, and climate resilience. Our findings indicate the potential of double cropping for achieving these three goals. This has the potential of reverting some of the negative effects of climate change on agriculture (e.g., Hsiang et al. (2013) and Burke et al. (2015)) as well as to help it to become a leading sector in climate change mitigation (e.g., Northrup et al. (2021)).

In this context, subsidizing the adoption of this type of technologies might be an important tool for governments to promote a just transition in agriculture. Nevertheless, designing the correct subsidies requires a better understanding on the constraints for double cropping adoption. First, it is important to understand to what extent farmers are internalizing the long-term benefits of adopting double cropping, in particular, and sustainable technologies, in general. Second, if they are not internalizing this, it is important to understand the drivers of their behavior (Atkin et al. (2017). Are they uniformed about the technologies' benefits (e.g., Jacopo et al. (2020))? Are they present-biased (e.g., Duflo et al. (2011))? Or, alternatively, do lack access to credit or insurance to precludes adoption (e.g., Karlan et al. (2014))?

Proper policies will depend on the response to these questions. For instance, intense training (e.g., Grimm and Luck (2020) and Beaman et al. (2021)) or farmer-to-farmer technology extension (e.g., Kondylis et al. (2017) or Bragança et al. (2022)) might reduce information barriers while earmarking more resources for "low-carbon agriculture" as proposed by Brazil's Low Carbon Agriculture (ABC) Program (which now represents only 2% of total rural lending) might reduce credit constraints. Regardless the mechanism, the evidence presented in this paper clearly documents the potential of sustainable technologies to help transform agriculture in a way that helps it to simultaneously meet climatic and development goals.

2.8 Appendix

Figure 2.9: **Fire occurrences by month in selected sample.**

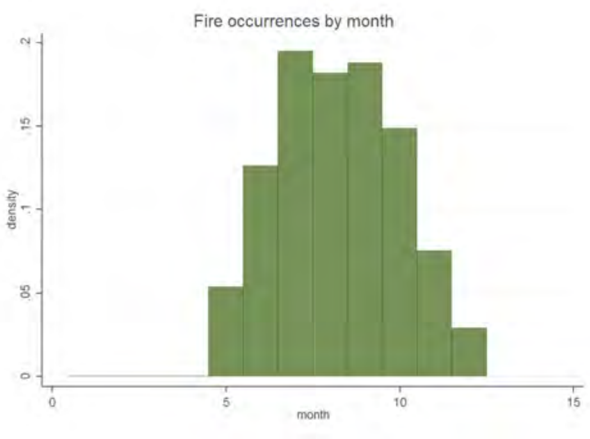
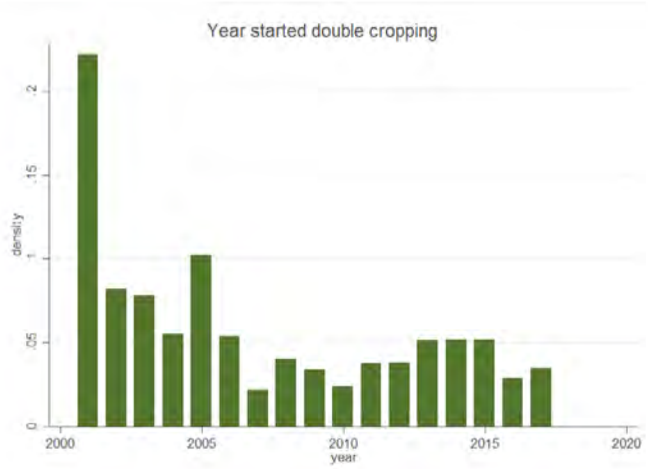


Figure 2.10: **Distribution of pixels by year that started double-cropping.**



3
Waiting time, Wasted time: Increasing State Capacity in Health Care Delivery

Amanda de Albuquerque (PUC-Rio)
Janeth Dula (Ministry of Health - Mozambique)
Margaret McConnell (Harvard)
Sandra Sequeira (LSE)
Maria Steenland (Brown University)

Abstract

Provision of health services is one of the greatest challenges for the government of Mozambique, being one of the countries with the highest HIV prevalence in the world (12.3%) and worst maternal mortality rates. Even though the country has overcome challenges in initially enrolling patients in treatment, patients' retention to treatment is currently a major barrier to control the spread of HIV - only 66% of patients who start treatment remain active after 12 months of enrolling in treatment.We hypothesize that poor quality and general unresponsiveness of services provided at public health clinics can be an important reason for low patient retention to treatment. Through an RCT at 80 health centers, we test whether a managerial intervention that implement an appointment scheduling can increase patients' adherence to medical treatment and also improve quality of care from the providers' side. We find heterogeneous effects, with the intervention affecting more positively patients enrolled for longer periods in antiretroviral therapy (ART) treatment. Moreover, even though patients do not report improvements in their perception on their patient experience visiting the facility, we see relevant improvements in performance of clinical procedures during antenatal care visits.

3.1
Introduction

Long waiting time in public health clinics is a long-standing problem in low-income countries. In this paper we hypothesize that poor quality and unresponsiveness of the healthcare system can be an important reason for low patient adherence to treatment. Existing WHO guidelines state that reasonable waiting time and prompt attention are key components of responsive health systems, as long queues can lead to the perception of poor-quality care and pressure on providers, affecting patients' behavior and health outcomes. However, few studies have directly examined how to improve patient experience in settings extremely constrained in human and financial resources, and its impact on key outcomes such as the utilization of care and the quality of health care delivery (Contreras-Loya et al. (2021); Dunsch et al. (2021); Atnafu et al. (2015); Mahomed and Bachmann (1998)). We test whether a managerial intervention at primary healthcare clinics in four provinces in southern Mozambique can decrease waiting time and increase patients and providers' satisfaction, affecting HIV retention in care rate.

The current first-come first-serve model dictates that patients can only be seen at a public health center if they arrive in the early hours of the morning, at 7 am or even before the center is open. Data from the pilot study we conducted between 2016-2017 shows that 66% of patients seeking antenatal care arrive at the clinic before 8 am, and by 10am 94% of all patients have arrived. Although queues start early in the day, patients can spend several hours waiting before being seen (the average waiting time in our pilot project was over 4h, for a consultation that would last on average 12 minutes). From a patient perspective, long queues compromise the effectiveness of the care provided as it can signal that the national health system is disrespectful and unresponsive to the needs of the patients, weakening the relationship between the patient and the system. From a provider perspective, long queues also have a negative effect. Under pressure and stressful settings, health providers may pay less attention to each individual case and neglect relevant procedures.

This coordination failure that results in long waiting times can be particularly constraining for patients who need to seek frequent care, such as pregnant women or patients with chronic diseases such as HIV. Indeed, these two groups are the main target of the Mozambican national health system structure. First, being one of the countries with the highest HIV prevalence in the world, ranking 8th with a rate of 12.3% (2016 data), the HIV program receives the biggest share of the health sector funds. The significant investments aimed at increasing coverage of HIV treatment in the past decade have been quite successful. The share of HIV positive patients who initiated antiretroviral therapy (ART) has increased from 13% in 2010 to 81% in 2021, with 96% of the health clinics providing HIV treatment (Ministry of Health, 2021).

However, even though the government has overcome challenges regarding testing and enrolling HIV patients in treatment, patient retention is currently the major obstacle to control the spread of the disease. Retention in care is key because the use of ART reduces the chance of transmission to others and because poor adherence can lead to ART resistance. Notwithstanding, only 66% of patients who start treatment remain active after 12 months of starting the treatment. And this rate continues to drop in the following years, with a retention rate of 49% at 36 months (Ministry of Health, 2015), a rate that is among the lowest in Sub-Saharan Africa (Global AIDS Monitoring 2018). A meta-analysis of studies conducted in 42 low- and middle income countries in Africa shows that, after 36-months of follow-up, only 65% of those on ART were retained on treatment (Fox and Rosen (2015)).

Second, while the majority (91%) of women visit a health center to seek antenatal care (ANC) over the course of their pregnancy, only about half (55%) receive the WHO-recommended minimum four antenatal care visits (Demographic and Health Survey Mozambique, 2011). On the technical side, even when women do receive the recommended number of antenatal care visits, they do not always receive high-quality care as core procedures do not always take place. For example, only 43.6% of women receive the necessary three doses of intermittent preventive treatment for malaria, just 51% of HIV+ pregnant women receive antiretroviral treatment, and only 18.6% of HIV+ pregnant women receive care ensuring the prevention of mother-to-child transmission of HIV (IMASIDA, 2015).

To understand whether improvements in the management of patient flow in public clinics could positively affect both patients and providers, we conducted a randomized controlled trial in 80 high-volume public health clinics. We aimed to test whether an appointment scheduling system could be effective to reduce waiting time, improve patients' and provider's satisfaction and affect health outcomes. Half of the clinics were selected to the treatment group in which all patients enrolled in HIV-treatment and pregnant women seeking antenatal care were given a date and a specific time interval when they should return to seek treatment. The remaining clinics were assigned to the control group, which continued with the standard of care where patients wait in line for a first-come first-serve visit.

Our intervention proved to positively affect both patients and providers. First, we found significant results on the Medication Possession Ratio (MPR), a widely used measure of adherence to antiretroviral therapy. The intervention had a heterogeneous effect regarding the years enrolled in ART treatment. For newly enrolled patients (who enrolled into ART after the scheduling system was already in place), the intervention led to an increase of 4.4% on average on the probability of having adequate

MPR across visits when compared to the control group (3.2 pp). For patients longer in treatment (enrolled before 2017), the effect is three times bigger, with an increase of 12.2% relative to the control group. Moreover, although the intervention had no effect on the probability of missing the day and being delayed for a ART refill pick-up for the newly enrolled patients, it caused a decrease of 20% compared to the baseline mean for patients on the control group for the older cohorts.

Second, from the provider side, the intervention was successful in improving their performance regarding quality of care provided during ANC visits. The scheduling system increased in 8.2 pp the share of "extra" procedures performed during a first ANC visit, which represents an increase of 17.7% relative to the control mean. This is consistent with the fact that the design of the invention allows providers to have more time and be less stressed in the first two hours of the day, when there is typically the highest peak of patients. Finally, relative to implementation effectiveness, we present evidence that the system was successful in decreasing the peak of patients on specific days of the week (Mondays). Moreover, one major concern about the intervention is that patients would self-select into treatment, switching from the control group to the treatment one, as previous evidence shows that patients can self-select into better managed clinics (McConnell et al. (2016)). We show that such unintended composition effect did not take place in our setting.

A broad literature exists on how to improve public service delivery by motivating civil servants' performance improvements. Although there is interesting evidence on how the design of the selection process affects the pool of selected officials (Deserranno (2019); Ashraf et al. (2014, 2020); Dal-Bó et al. (2013)), the interventions designed to increase performance once officials are hired mainly involve financial incentives (Donato et al. (2017); Khan et al. (2016); Miller et al. (2012); Basinga et al. (2011); Olken et al. (2014); de Walque et al. (2015)) or costly monitoring infrastructures (Dal-Bó et al. (2021); Olken (2007); Callen et al. (2020); Dhaliwal and Hanna (2017); Pomeranz (2015); Muralidharan et al. (2016)). For instance, even the evidence on the effect of monetary incentives in the context of Education finds markedly mixed results (Duflo et al. (2012); Lavy (2002); Muralidharan and Sundararaman (2011); Glewwe et al. (2010)). We complement the literature that highlights non-financial mechanisms to improve public agents performance (Ashraf et al. (2014); Khan et al. (2019); Bertrand et al. (2019)), presenting evidence on how management practices can affect performance of healthcare providers.

Second, this paper contributes to the literature establishing a relationship between management practices and health outcomes, which has been primarily drawn from high-income countries and has poorly been explored in low-income countries (Contreras-Loya et al. (2021); Dunsch et al. (2021)). While there is a growing literature suggesting that managerial capital is associated with significant productivity increases in the private sector (Bloom et al. (2014); Tsai et al. (2015); Jiang et al. (2009)), less is known about how it can affect the quality of service in the public sector (Rasul and Rogger (2018), particularly in the developing world where levels of managerial capital tend to be lower. Overall, findings suggest that management practices are both strongly related to a clinics's performance and provide a unique target for quality improvement interventions reaching across multiple clinical domains (Lega et al. (2013); Hoof et al. (2012)). The findings from our research enhance these findings, bringing knowledge on the costs imposed by inefficient management of health services and its impact on patient demand for health care.

Finally, we provide some of the first evidence about whether a managerial intervention improving patients' experience can impact patients' behavior regarding adherence to medical treatment. Previous studies conducted in Sub-Saharan Africa have shown that appointment scheduling can be effective in reducing waiting time and improving patient satisfaction (Atnafu et al. (2015); Mahomed and Bachmann (1998)). However, these studies have not measured the effect on health indicators, such as our outcomes on treatment adherence and quality of care provided. In settings where digital scheduling is possible, the system proved to positively affect not only patients affected by the intervention, but also patients ineligible to be scheduled, due to better patient flow management related to timely cancellations and re-scheduling capacity (Boone et al. (2022)).

The rest of the paper proceeds as follows. Section 3.2 presents background knowledge on provision of healthcare for HIV patients and pregnant women seeking ANC. Section 3.3 explains details of the intervention implemented through an RCT and Section 3.4 describes the different datasets used in our analysis. Section 3.5 presents our empirical strategy to evaluate the effect of the intervention on both patient and providers, along with the effectiveness of the implementation. Section 3.7 concludes by presenting the relevant policy implications of our findings.

3.2 Background - Patient Flow Management

1. National Health System. Provision of health services is one of the greatest challenges for the government of Mozambique. The country is among the countries with the worst health indicators in the world, ranking 170th in under-5 mortality rate, 163th in maternal mortality ratio and 185th in life expectancy (World Development Indicators). With the concentration of private health investment happening in Maputo and few other provincial capital cities, the population living outside major cities relies only on public provision of health, which consists of over 1600 primary care clinics and 60 hospitals for over 31.3 million people. Besides having an insufficient number of clinics to provide health services, Mozambican clinics face serious constraints on human resources. The country still needs to increase its physicians-population ratio 7 times to meet WHO's minimum recommendations and this gap is not expected to change in the short run. Finally, being one of the poorest countries, an important barrier to increase capabilities of the national health system is financing. The sector is systematically underfunded and dependent on external resources, with foreign aid accounting for over 55% of the Ministry of Health budget (UNICEF 2016).

2. HIV. Despite recent progress in enrolling patients living with HIV on antiretroviral treatment (ART) and decreasing maternal mortality rates in Mozambique, low adherence to treatment threatens to undermine these advances. Previous research suggests that an adherence rate of 95% to ART is required in order to achieve maximal viral suppression and lower the rate of opportunistic infections (Turner (2002); Haas et al. (2016); Bisson et al. (2008); Paterson et al. (2000)). From an individual perspective, retention in care is relevant as ART can decrease the concentration of virus in the blood and can ultimately render HIV-positive people sexually noninfectious (Bavinton and Rodger (2020); Cohen et al. (2011)). Moreover, there is firm evidence of the positive effect of antiretroviral drugs in the prevention of mother-to-child transmission (Dao et al. (2007)).

Retention in ART is also relevant as poor adherence can lead to ART resistance (Sethi et al. (2003); Bangsberg et al. (2003); Harrigan et al. (2005); Parienti et al. (2004)). Drug resistance during first-line therapy increases the risk of HIV-related transmission, morbidity and mortality (Harries et al. (2001)). As a result, poor adherence increases the need for second-line treatment options, which are often limited, considerably more costly, require more complex regimens, and can be associated with new or unknown toxicity. Consequently, in a context in which converting to second-line ART therapy may be an individual's last chance of treatment, it is relevant to prevent resistance emergence (Meresse et al. (2014)).

In addition to individual impacts, retention in care is critical as wider and earlier initiation of ART can reduce population-level incidence of HIV. Low adherence on the other hand can significantly and negatively impact the health sector and the economy as a whole. Previous research shows that ART can improve the productivity (measured as decreased absenteeism) of workers in the short, medium and long-run (Habyarimana et al. (2010)). From a human capital development perspective, there are around 2.1 million people living with HIV in Mozambique, 125,000 of which are children (aged 0 to 14), and over 35,000 people died due to HIV in 2021.

There are many reasons behind low adherence to HIV treatment. First, there are patient-level factors, such as low education and perceived stigma. Second, there are institutional factors such as the lack of privacy at health clinics, poor healthcare professionals' attitudes, poor communication, poor quality of services, and the long time spent in queues to receive treatment (Schacht et al. (2014); Govindasamy et al. (2012); Chesney (2000)). Even though privacy, respect shown by staff and waiting times are not service attributes that may seem to be clinically necessary, they can influence patients' perceptions and their willingness to adhere to treatment (Hanefeld et al. (2017)). Previous WHO research shows that patients' decision not to seek needed medical care are related to quality reasons, as opposed to cost of care or distance to clinics (Kruk et al. (2018)).

3. Maternal health. Antenatal care (ANC) is a critical introduction to the continuum of maternal and newborn health care. Access to affordable, high quality antenatal care offers the opportunity to inform women about potential danger signs to look for during their pregnancy, to identify and treat illnesses such as malaria or tuberculosis (TB), and to promote healthy behaviors such as healthy nutrition and breastfeeding. Medical monitoring during the first trimester of pregnancy is essential to identify factors that characterize a risky pregnancy and, under pressure, health providers may pay less attention to each individual case and neglect procedures relevant to the identification of risky cases. Indeed, only 40% of women who attended an antenatal care visit in Mozambique were informed by the nurse of signs that indicate possible complications during pregnancy (MOH 2012).

Mothers attending antenatal care likely have numerous other responsibilities - the average woman in Mozambique has 5.6 children. Furthermore, the hassle costs of antenatal care may be relatively salient compared to the benefits of care, which occur largely in the future. Moreover, ANC is often the first interaction a pregnant woman has with the health center. The initial experience of waiting all day for poor-quality care is likely to have significant downstream negative effects. A perception of non-responsive care may also weaken the relationship between patient and provider, leading patients to be less likely to comply with medical advice. In the case of maternal health, high-quality maternal care is associated with institutional delivery. Women who have negative experiences during antenatal care may therefore be less likely to return for delivery in the clinic.

4. Appointment scheduling. Patients receiving HIV treatment need to visit health clinics frequently to obtain refills and clinical care. They can only obtain ART refills by visiting a public health clinic, as this medicine is not provided in private pharmacies. Most patients receiving HIV treatment should visit the health clinic monthly for refills of ART and every three months for clinical care. Similarly, WHO recommends pregnant women to attend antenatal care visits every 30 days during the first 8 months and then every 15 days when gestational age reaches the 34th week.

Currently, the experience of seeking care in public clinics often involves waiting all day in a queue. According to survey data from 2012, 74% of individuals responding to a survey about problems with health systems report that they have experienced very long wait times in public clinics (Afrobarometer, 2012). The opportunity cost of these patients' time is often not trivial. Patients incur indirect costs such as foregone income for the day (if their employer agrees to let them miss a day of work), child care and/or they have expenses with food as they usually leave home without even having breakfast (Gong et al. (2019)).

Like most developing countries, tools for managing patient flow in Mozambican public clinics, such as an appointment system for scheduling next visits, are almost non-existent. There is no universal policy from the Ministry of Health for how to prioritize the order of the queue with most clinics taking patients on a first-come, first-served basis. Patients are provided with a return date for their next visit, without an appointment time. As a result, most patients arrive in the early hours of the day, leading to an inefficient coordination failure: patients queue for hours from early in the morning, particularly on Mondays and Fridays [1], even though the clinics have very few patients in the early afternoon or during the remaining weekdays. The challenge therefore appears to be one of mismanagement

[1]See Figure 3.4. This usually happens as providers schedule patients to come 30 days ahead without checking on the calendar which day of the week that will fall. Since primary health clinics are closed during weekends, this forces patients assigned to Saturday and Sundays to either come the business-day before (Friday) or the following one (Monday).

of existing resources as opposed to the lack of resources altogether. This is compounded by the fact that it rests on ingrained social norms on queuing for social services. In fact, a first come first serve system has been utilized for all other types of public services that require regular interactions for several decades.

The system of queues represents a misuse of the most needed resource of the healthcare system which is human capital. Data from the pilot study shows that providers, who were supposed to work until 3h30pm, usually stop seeing patients around 12am, with 80% of providers seeing their last patient before 12am and none of them seeing a patient after 2pm. From the providers' perspective, an uneven distribution of patients along the hours of the day has a significant impact on healthcare provision. Because almost all patients arrive in the first 1-3 hours of the morning, providers are forced to see patients under stressful conditions.

Moreover, concentration of patients in a short period of time results in shorter consultations and empowers providers to deny service delivery to patients after a certain time of the day. Patients then face not only significant financial and personal costs when undergoing treatment but they must also deal with significant uncertainties, such as not knowing whether they would be seen at all. The social norm is to arrive at the clinic early in the morning to minimize the waiting period, and most patients acknowledged that not arriving early enough could result in being turned away (Gong et al. (2019)).

3.3 Intervention

Sampling frame. Due to lack of microdata from ANC patients, we constructed our sampling frame based only on service delivery to patients enrolled in ART (power calculation can be found on Appendix 3.8.3). To target high-volume clinics, we ranked the 230 clinics providing HIV treatment in Mozambique's four southern provinces (Maputo, Maputo city, Gaza and Inhambane) by the average number of HIV clinic visits per day. We selected the top 80 clinics, getting to a sample of clinics that had an average of at least 17 HIV visits per day.

We then imposed a buffer zone of 2km between clinics to avoid treatment contamination due to patient self-selection into treated clinics, even though we expected that switching among treated and control clinics would be extremely rare because patients' files are kept in physical folders at the clinic they enrolled in ART, and patients cannot easily request to transfer them.[2] With an average of over 11,000 HIV patients enrolled in treatment in each clinic, our sample covers over 50.5% of all patients enrolled in ART in these 4 provinces (total 170,160 patients). Figure 3.5 in the Appendix presents the location of the clinics in the map.

Intervention. The theory of change behind the designed intervention is that improvements in the patient distribution along hours of the day and days of the week would i) improve patient experience, reducing the opportunity cost of seeking clinical care and ultimately improving adherence to treatment and retention in care; and ii) improve the working environment for health providers, increasing the quality of care provided.

In partnership with the Ministry of Health, we designed a scheduling system with time for appointments for HIV patients enrolled in ART and pregnant women seeking antenatal care in public health clinics. Before the intervention, patients were provided with a return date for their next visit, chosen by the health provider at the end of their ANC visit or ART refill pick-up, but no time of that date was assigned for their next appointment. Our intervention introduced a scheduled appointment time for pregnant women seeking ANC and HIV patients on ART. Providers, who kept an appointment book in the consultation room or at the pharmacy, informed each patient of the date when they should return and checked the appointment book on that day. In the appointment book, for each day of the year, there were one-hour blocks with limited places for patients per block (for example, 6 per hour). With this design, we expected patients to be seen within one hour of their arrival. The patient chose the block-hour that better suits her and the provider then recorded it on the patient's appointment card and also in the appointment book. Images of the card and the book are shown in Figure 3.7 in the Appendix.

Randomization was stratified by province. Half of the clinics were selected to the treatment group in which all patients enrolled in ART and seeking ANC were given a date and a specific time interval when they should return to seek treatment. The remaining clinics were in the control group, which continued with the standard of care where patients wait in line for a first-come first-serve visit.

Due to logistics, we organized clinics for the implementation of the intervention in two groups, depending on the province they were located. In the first group (Maputo Cidade and Maputo Province), 21 clinics started to use the appointment scheduling on October 26th 2020. In the second group

[2] We present evidence in Section 2.5 that there was no composition effect regarding the total number of visits per clinic after the intervention.

(Gaza and Inhambane), 19 clinics started the scheduling on December 7th 2020. Figure 3.6 in the Appendix presents the timeline of the data collection and implementation activities.

A special feature of the intervention for the ANC services is that the appointment book was slightly different from the HIV one, to accommodate a common practice in most clinics in which ANC patients coming for their first ANC visit are given priority in terms of queuing, being the first one to be seen even though they might have arrived after a patient that came for their follow-up visit. As the first ANC visit is extremely important in terms of clinical procedures (especially to check HIV status of the mother and risky conditions on previous pregnancies), the Ministry requested all clinics to implement this rule on giving priority to these patients. This led us to design in each page of the appointment book a 2-hour block in the first two hours of the morning, in order to incorporate this practice (see Figure 3.7 in the appendix for an illustration on the final design of the appointment book).

3.4 Data

To examine treatment effects on both patients and providers, we rely on a combination of survey and administrative data from the Ministry of Health. Due to Covid-19, we could not run a baseline to interview patients, as originally planned in our Pre-Analysis Plan. Results presented in this research use data from the endline we conducted 12 months after the intervention.

1. HIV administrative data. We collected administrative data extracted from electronic records of the Ministry of Health from all HIV patients enrolled in ART from 2001 until September 2021. These patient visit-level records list the date that each patient was supposed to visit the clinic for a consultation with a clinician and the date that they were supposed to visit the pharmacy for an ART refill pick-up, the actual dates in which they visited the clinic, and also the amount of pills that were given at each visit. We used these data to create a longitudinal dataset that lists the dates of all scheduled and actual visits to pick-up ART refills.

With this dataset we construct three outcomes related to patients' adherence and retention in care: 1) dummy whether the patient is delayed ($\geq$ 7 days delayed to pick-up ART refills); 2) dummy whether the patient present a loss to follow-up ($\geq$ 60 days delayed to pick-up ART refills); and 3) a dummy indicating whether the Medication Possession Ratio (MPR) is above 95%. The MPR is the proportion of a time period where a medication supply is available. Here, we calculated it as the number of pills a patient received in his last visit and the amount of days between the last pick-up and the following one.

Although we have data on clinical visits and ART pick-ups, we focus our analysis using data from ART refills pick-ups at the pharmacy, as these metrics on patient adherence refer to medication possession rather than procedures received during a clinical visit. Moreover, previous research shows that pharmacy refill adherence is a stronger predictor of virological failure than self-reported adherence (Sangeda et al. (2014)) . We chose the three outcome variables used to measure the effect on treatment adherence based on previously validated metrics in the health literature (Messou et al. (2011); Ridgeway et al. (2018); Martinez et al. (2014); Tirivayi (2012)).

Regarding the impact of Covid-19 in the implementation of the intervention, Figure 3.8 in the Appendix shows how Covid-19 represented a shock in the way clinics used to assist patients enrolled in ART. Following WHO recommendations to avoid agglomeration of patients, the Ministry mandated clinics to give a higher number of pills to patients in order to decrease the frequency and number of visits they would make to the clinic. Because of this major change, our analysis only considers data from the period after the Covid shock (April 2020), until September 2021 (when adminsitrative were available).

We restrict our analysis to a subsample of patients registered in our selected clinics. To ensure we had a comparable group of patients affected by the intervention, we measured the effect of the intervention on the group of patients that came for a refill pick-up between 0-60 days after the beginning of the intervention. We chose this period as most patients were scheduled to return for a pick-up 60 days after the current pick-up, which implies that during the first two months after the implementation of the scheduling system all patients that came for a pick-up were being scheduled for the first time - which would affect only the following visit. We describe the characteristics of the sample in subsection below, where we present the balance statistics between treatment and control groups.

2. ANC exit interview survey. To measure the effect of the intervention on quality of care, we conducted short exit surveys with a random sample of patients that visited the clinics seeking ANC. We decided to interview only patients from ANC services using the exit interview instrument as there are specific guidelines for clinical procedures that should happen during an ANC visit. In comparison, for HIV patients, the procedures are less standardized, varying according to patients' clinical condition.

Enumerators were instructed to recruit only 2 women per 2-hour window to allow us to capture quality of care along different hours of the day. With a sample of 1,933 patients, this tool allowed us to check whether providers were complying with the clinical procedures guidelines during ANC – self-reported by patient on exit interview. Table 3.9 in Appendix lists the 21 procedures we assessed during the exit interviews. Besides asking whether the patient received each of the 21 procedures listed on the Ministry's guidelines, we also assessed patients' perception with care received, such as satisfaction regarding waiting time, whether they incurred income loss to visit the clinic that day and their willingness to deliver at that clinic.

3. Controls. To ensure balance on clinic characteristics at baseline, we used data from SARA 2018 (Service Availability and Readiness Assessment). Using a methodology developed by the WHO, this health facility assessment tool assesses the service availability and readiness among the whole population of public clinics in Mozambique. Last occurring in 2017, this major survey generated reliable information on service delivery capacity at the clinic level. With this dataset, we could check whether clinics were comparable in terms of availability of basic equipment, essential medicines, diagnostic capacities, and readiness of health facilities to provide basic health-care interventions, considering their human and infrastructure resources. Information on human resources at the clinic level was collected by the research team at the time of the construction of the sampling frame (2018), as this data is constantly changing due to high turnover across clinics and the administrative data was outdated. We collected information on the total number of clinicians providing healthcare at the clinic, identifying the ones specifically assigned to see HIV patients and the number of rooms in which patients could be seen.

3.4.1 Balance statistics

Tables 3.1 and 3.2 present summary statistics of clinics and patients' characteristics, respectively. Regarding clinics' characteristics, they have on average 11,679 patients currently enrolled in ART, with on average 26.5 patients coming daily for a refill pick-up in 2020. These clinics are located mainly in rural areas, consistent with the fact that 62% of the Mozambican population lives in rural areas. Comparing the score for general infrastructure versus HIV dimensions, we see that the clinics are better scored in providing HIV related services. With on average 7.3 clinicians per clinic, the majority of the staff (4.8) is assigned to see HIV patients. Regarding balance across clinics in treatment vs. control groups, they are balanced on all dimensions, such as the average number of pick-up visits per day, the total number of patients enrolled in ART, whether they are located in an urban area, whether viral load testing can be done in the clinic, and number of staff providing care for HIV patients.

Table 3.1: **Summary and balance statistics - Clinics' characteristics**

	All clinics		Control			Treatment			Difference
	N	Mean	N	Mean	SE	N	Mean	SE	(1)-(2)
HIV services									
Total patients enrolled in ART	80	11,679	40	10,871	[2,287]	40	12,489	[1,266]	-1,619
Average pick-up visits per day (baseline)	80	26.502	40	24.653	[5.157]	40	28.352	[2.983]	-3.699
Rooms chronic patients	68	3.294	33	3.212	[0.643]	35	3.371	[0.248]	-0.159
Clinicians seeing HIV patients	64	4.843	31	4.871	[0.779]	33	4.818	[0.753]	0.053
Viral load testing capacity (SARA)	80	0.362	40	0.350	[0.142]	40	0.375	[0.133]	-0.025
HIV counseling and testing readiness index (SARA)	79	0.813	40	0.819	[0.018]	39	0.808	[0.054]	0.011
HIV/AIDS care and support readiness index (SARA)	79	0.725	40	0.733	[0.037]	39	0.718	[0.024]	0.015
ART all items (SARA)	79	0.278	40	0.225	[0.098]	39	0.333	[0.105]	-0.108
ANC services									
Total ANC visit per month	78	404.12	39	412.7	[49.3]	39	395.2	[39.4]	17.5
Total ANC 1st visit patients per month	78	124.1	39	124.6	[15.1]	39	123.5	[11.9]	1.1
ANC readiness index (SARA)	79	0.643	40	0.635	[0.042]	39	0.651	[0.057]	-0.016
General									
Clinicians total	70	7.3	33	8.212	[1.958]	37	6.486	[0.778]	1.726
Urban	80	0.375	40	0.350	[0.143]	40	0.400	[0.177]	-0.050
General service readiness index (SARA)	79	0.687	40	0.678	[0.022]	39	0.697	[0.011]	-0.019
Basic equipment domain score (SARA)	79	0.837	40	0.821	[0.022]	39	0.855	[0.009]	-0.034
Infrastructure - Soap and running water or alcohol based hand rub (SARA)	79	0.544	40	0.525	[0.049]	39	0.564	[0.048]	-0.039

Notes: Control group means are reported in column (4) and treatment group in column (7). Standard deviations are reported in square brackets. Mean differences between control and treatment arms reported in column (9), with standard errors clustered by clinic. Significance on the difference based on p-value as *** p<0.01, ** p<0.05, * p<0.1.

Relative to patients, Table 3.2 shows that the majority of our subsample of patients in ART are women, accounting for 63.3% of all patients. Half of them completed primary school and the average age is 36.2. They have been enrolled in treatment for 2.7 years on average, coming for 4.1 pick-up visits after Covid-19 but before the intervention started. Examining the retention in ART, they are on average delayed in 9.1% of their refills pick-up visits, with an average delay of less than 1 day. However, they present a high MPR (average 1.52), showing that they might be covered with medication even in the times they might not come on time for the next pick-up.

Table 3.2: **Summary and balance statistics - Patients' characteristics**

	All clinics		Control			Treatment			Difference
	N	Mean	N	Mean	SE	N	Mean	SE	(1)-(2)
HIV patients (administrative data)									
Years in treatment	25,388	2.744	11514	2.879	[0.115]	13874	2.633	[0.093]	0.246*
% newly enrolled patient (post-intervention)	25,388	0.107	11514	0.101	[0.007]	13874	0.112	[0.006]	-0.011
Woman	25,388	0.633	11514	0.633	[0.008]	13874	0.634	[0.006]	-0.000
Age	25,388	36.191	11514	36.633	[0.254]	13874	35.826	[0.375]	0.807*
Education - Primary school	12,271	0.544	5787	0.548	[0.025]	6484	0.541	[0.021]	0.007
Household size	18,638	3.151	8257	3.242	[0.129]	10381	3.079	[0.164]	0.163
Number of kids	18,606	1.371	8238	1.468	[0.091]	10368	1.295	[0.107]	0.173
For older cohorts									
Number of ART refills pick-up (baseline)	22,697	4.151	10372	4.313	[0.164]	12325	4.013	[0.080]	0.300
% delayed pick-ups (baseline)	22,697	0.091	10372	0.093	[0.009]	12325	0.090	[0.008]	0.003
Average number of days delayed (baseline)	22,697	0.979	10301	0.541	[0.584]	12243	1.349	[0.403]	-0.808
% loss to follow-up pick-ups (baseline)	22,697	0.009	10372	0.008	[0.001]	12325	0.009	[0.001]	-0.002
Average MPR (baseline)	22,697	1.524	10284	1.542	[0.073]	12201	1.509	[0.132]	0.033
ANC patients (exit interviews)									
Age	1,933	25.331	874	25.207	[0.347]	1059	25.433	[0.347]	-0.226
Read and write	1,933	0.869	874	0.849	[0.034]	1059	0.887	[0.034]	-0.038
Education - high school	1,933	0.247	874	0.239	[0.030]	1059	0.253	[0.030]	-0.014
Married	1,933	0.657	874	0.666	[0.042]	1059	0.650	[0.042]	0.016
Num. kids	1,933	1.265	874	1.244	[0.079]	1059	1.283	[0.079]	-0.040
Num. kids under 5 in the hh	1,933	0.618	874	0.620	[0.042]	1059	0.616	[0.042]	0.004
Income generating activity	1,933	0.165	874	0.165	[0.024]	1059	0.165	[0.024]	-0.000
Dummy 1st ANC visit today	1,933	0.268	874	0.280	[0.020]	1059	0.258	[0.020]	0.023
Number of ANC visits	1,933	2.90	871	2.883	[0.071]	1039	2.933	[0.071]	-0.050

Notes: Control group means are reported in column (4) and treatment group in column (7). Standard deviations are reported in square brackets. Mean differences between control and treatment arms reported in column (9), with standard errors clustered by clinic. Significance on the difference based on p-value as *** p<0.01, ** p<0.05, * p<0.1.

Comparing patients in treatment and control groups, they are well-balanced on a range of important characteristics, namely demographic characteristics such as gender, education, household size and number of kids, as well as our outcome variables at baseline. However, they slightly differ in terms of years in treatment (the control group patients are 0.25 years longer in ART than the patients in the treatment group) and age.

3.5 Empirical Strategy

First, to capture the impact of the scheduling system on patients, we measure the effect of the intervention on treatment adherence. Given the stratified random assignment of our intervention, we can obtain unbiased estimates of the effect of the scheduling system by estimating the following equation:

$$ART\ treatment\ adherence_{vpct} = \theta\ Post_t \times Treatment_c + \delta_c + \gamma_t + \varepsilon_{pct} \quad (3\text{-}1)$$

where $ART\ treatment\ adherence_{vpct}$ refers to one of the outcome variables for HIV patients, v indexes each visit of patient p from clinic c at month t; δ_c controls for clinic fixed effects; γ_t represent time fixed effects. θ is the coefficient of interest and captures the average effect of the intervention based on intention to treat (ITT). ${}_t$ refers to any visit that happened 30 days after the beginning of the intervention. In all regressions, we cluster standard errors at the clinic level since treatment assignment was randomized at the clinic level.

We estimate this equation for different cohorts of patients enrolled in ART, considering the period between April 2020 (after Covid-19) until September 2021 (due to data availability). Our sample is composed of all patients that did a pick-up ART refill visit between 0-60 days after the intervention started,[3] which accounts for 25,203 patients in our 80 selected clinics. Among those patients, we separate the patients that started treatment right after the start of the intervention from patients that were previously enrolled in ART. Because newly enrolled patients do not present pre-intervention data, we run a different estimation for them:

$$ART\ treatment\ adherence_{vpcdt} = \theta\ Treatment_c + \delta\ X_c + \delta_d + \gamma_t + \varepsilon_{vpcdt} \quad (3\text{-}2)$$

where $ART\ treatment\ adherence_{vpcdt}$ refers to the outcome variable regarding visit v of patient p from clinic c located at district d at month t; ${}_c$ controls for clinics' characteristics (urban, number of patients in ART, HIV diagnostic capacity index, ANC readiness index, laboratory exams capacity, number of clinicians, hand wash infrastructure for patients). δ_d refers to district fixed effects and γ_t represent time fixed effects.

We use three different outcomes to measure the effect regarding treatment adherence. First, for each visit we create a dummy whether the patient is 7 days delayed to their pick-up date. Second, since being delayed does not mean the patient will run out of pills - it will depend on the amount they

[3]The scheduling system starts effectively to work not in the following day of the beginning of the intervention, but actually only after a critical mass of patients that were supposed to come pick-up their ART refills were given an appointment time in their previous pick-up visit. Because of this special feature and the short period of post-intervention data we have, our post variable is a dummy that turns on the day that at least 50% of patients supposed to come that day had a previous visit when the scheduling system was already in place.

took home in their previous visit - we create a dummy indicating whether the medication possession ratio (MPR) is 95%, which is a standard proxy for the patient being effectively active on treatment. Finally, we use a more strict outcome to measure retention in care by creating a dummy to indicate whether the patient gave up on treatment, which is known as the loss to follow-up and is defined as any 60-day delay to pick-up ART refills.

We complement the analysis on treatment adherence using data from the exit interviews with ANC patients to measure the impact of the intervention on patients' overall experience. We estimate a similar regression to measure the effect of the intervention on patient experience:

$$Patient\ experience_{pc} = \theta\ Treatment_c + \alpha\ X_p + \delta\ X_c + \varepsilon_{pc} \quad (3\text{-}3)$$

where $Patient\ experience_{pc}$ refers to variables that capture patients' satisfaction regarding waiting time and how the long queues might affect patients' work (eg: whether they suffered income loss due to the need to attend an ANC visit that day).

Second, to measure the impact of the intervention on providers' performance, we use data from the exit interview with ANC patients, described in Section 3.4. Since we have a cross section of patients instead of a panel, all of which were interviewed after the start of the intervention, we estimate the following regression:

$$Quality\ of\ care_{pc} = \theta\ Treatment_c + \alpha\ X_p + \delta\ X_c + \varepsilon_{pc} \quad (3\text{-}4)$$

where $Quality\ of\ care_{pc}$ refers to the outcome variable of patient p from clinic c located at district $d.X_p$ controls for patients' characteristics (age, education, marital status, number of kids, and number of kids under 5 in the household), and X_c are the same set of controls as discussed above. Our main $Quality\ of\ care_{pc}$ variable is an index that represents the share of procedures realized among the 21 procedures listed on the ANC guidelines from the Ministry. Once again, the coefficient of interest is θ, capturing the ITT effect.

Finally, we estimate the effectiveness and unintended consequences of the implementation. First, we test whether the scheduling system was effective in mitigating a coordination failure on patient inflow with peaks of patients coming on Mondays and Fridays, estimating the following equation:

$$Week\ day_{vpct} = \theta\ Post_t \times Treatment_c + \alpha_p + \delta_c + \gamma_t + \varepsilon_{vpct} \quad (3\text{-}5)$$

where, for each day of the week (Monday - Friday), we estimate the equation where $Week\ day_{vpct}$ refers to a dummy on whether the visit happened in that day of the week. Finally, we test whether there is a side effect on the composition of patients across clinics, with patients from the control group clinics crowding in after the start of the intervention. To evaluate that, we run a regression on the number of patients coming each week to each clinics, as following:

$$Total\ pick\ ups_{ct} = \theta\ Post_t \times Treatment_c + \delta_c + \gamma_t + \varepsilon_{ct} \tag{3-6}$$

where $Total\ pick\ ups_{ct}$ represents the total number of ART refil pick-ups per clinic per week.

3.6 Results

In this section, we present the results of the estimates on ITT effects of the appointment scheduling, from patients and providers perspective. We estimate the direct effect of poor service quality (in the form of long queues) on treatment adherence, while further exploring the hypothesis that poor management of patient flows contributes to low quality of healthcare provided (specifically the number of clinical procedures accomplished). We finish this section by presenting the results regarding the effectiveness of the intervention to diminish the failure of scheduling patients for weekends (when the clinics are closed), allowing the patient inflow to be less concentrated on Mondays (the following business day after the mistaken weekend appointment).

3.6.1 Treatment adherence and patient experience

We estimate the impact of the appointment scheduling on treatment adherence following the specification presented in equation 3-1 for older cohorts, and in equation 3-2 for patients enrolled in treatment after the start of the intervention . Table 3.3 presents the impact of the intervention for both groups of patients regarding our first outcome variable, a dummy whether the patient was delayed (7 days) for a pick-up. Columns 1-2 refer to the impact on the newly enrolled patients, and columns 3-4 present the results for older cohorts. Columns differ across them by the set of included controls and fixed-effects, with our preferred specification presented in columns 2 and 4. The results points to no effect of the appointment scheduling, on average, on the probability of being delayed, regardless of how long the patients enrolled into treatment.

Table 3.3: **Effect on probability of being delayed**

	New patients		Older cohorts	
Dep. var.: P(delayed)	(1)	(2)	(3)	(4)
Treatment	-0.0106	0.00589	-0.00629	
	(0.0150)	(0.0163)	(0.0153)	
Post			0.0237	0.0596**
			(0.0393)	(0.0256)
Treatment x Post			0.00868	0.00889
			(0.0119)	(0.0111)
Observations	14,139	14,139	149,780	149,780
Adjusted R-squared	0.029	0.040	0.021	0.038
Number of patients	2,667	2,667	22,536	22,536
Mean dep. var. (control)	0.166	0.166	0.112	0.112
Month FE	Y	Y	Y	Y
District FE		Y		
Clinic controls		Y		
Patient controls				
Clinic FE				Y

Notes: This table reports the effects of the intervention on a dummy whether the patient was $\geq$ 7-day delayed to a ART refill pick-up. Observation unit a visit v of patient p at clinic c in month t. Columns (1) - (2) include the newly enrolled patients (who enrolled after the introduction of the scheduling system and thus do not have pre-treatment observation). Basic controls for this subsample include clinics' characteristics (urban, number of patients in ART, HIV diagnostic capacity index, ANC readiness index, laboratory exams capacity, number of clinicians, hand wash infrastructure for patients). Columns (3) - (4) include older cohorts in which we progressively include fixed effects (clinic and patient). Standard errors in parentheses are clustered at the clinic level.

Although being delayed for a refill pick-up represents a risk on the continuation of the treatment, as patients might run out of pills, the outcome that more safely ensures the patient is not at risk regarding treatment adherence is the medication possession ratio (MPR), which captures the period of time the patient is covered with pills available. Table 3.4 presents the effect of the intervention on the probability of the MPR from the last pick-up being ≥ 0.95, which means that since their last pick-up, the patient had pills to cover at least 95% of the days before their following pick-up. Our preferred specification in columns 2 and 4 present significant effects for patients both newly enrolled and older cohorts. On average, patients from the control clinics were safely covered with pills possession on 73.9% - 75.6% of the time. Thus, the intervention caused an increase in these rates of 3.2 pp for newly enrolled patients and 2.6 pp for older cohorts, which represents an average increase relative to the clinics in the control group of 4.4% and 3.5%, respectively.

Regarding retention in care, we estimate the effect of the intervention on the probability of giving up on ART. Table 3.5 shows the effect of the

Table 3.4: **Effect on Medication Possession Ratio (MPR)**

	New patients		Older cohorts	
Dep. var.: P(MPR >.95)	(1)	(2)	(3)	(4)
Treatment	0.0283**	0.0230*	-0.00870	
	(0.0132)	(0.0138)	(0.0160)	
Post			0.152***	0.139***
			(0.0213)	(0.0165)
Treatment x Post			0.0260**	0.0272**
			(0.0127)	(0.0130)
Observations	14,048	14,048	148,170	148,170
Adjusted R-squared	0.039	0.047	0.014	0.026
Number of patients	2,667	2,667	22,536	22,536
Mean dep. var. (control)	0.739	0.739	0.756	0.756
Month FE	Y	Y	Y	Y
District FE		Y		
Clinic controls		Y		
Clinic FE				Y

Notes: This table reports the effects of the intervention on a dummy whether patients' MPR was $\geq$ 95%. Observation unit a visit v of patient p at clinic c in month t. Columns (1) - (2) include the newly enrolled patients (who enrolled after the introduction of the scheduling system and thus do not have pre-treatment observation). Basic controls for this subsample include clinics' characteristics (urban, number of patients in ART, HIV diagnostic capacity index, ANC readiness index, laboratory exams capacity, number of clinicians, hand wash infrastructure for patients). Columns (3) - (4) include older cohorts in which we progressively include fixed effects (clinic and patient). Standard errors in parentheses are clustered at the clinic level.

appointment scheduling on a dummy of loss to follow-up, defined as any 60-day delay to pick-up the ART refill. We find no significant effect on average, neither for the newly enrolled nor for the older cohorts.

To investigate whether there are heterogeneous effects of the intervention, we focus on the group of older cohorts to further analyze how the year of enrollment in ART might correlate to the effect of the intervention. We break the older cohorts group according to the year in which those patients enrolled in treatment and estimate the same specification as before (equation 3-1). Figure 3.9 in the Appendix presents the distribution of patients by the year in which they enrolled into treatment. We see that there was a major change on service delivery in 2018, when the Ministry of Health started to implement the WHO recommendation of enrolling all HIV positive patients immediately in ART (regardless of viral load or clinical stage, which were the previous criterion). This strategy significantly increased treatment reach-out and had great impact on the inflow of patients coming to ART pick-ups in the following years, as can be shown in Figure 3.10 in the Appendix.

For patients enrolled in treatment before that change (which represents 11.2% of our sample), this was a negative shock on their experience visiting a clinic for pick-up, due to the significant increase in the volume of patients,

Table 3.5: **Effect on loss to follow-up**

	New patients		Older cohorts	
Dep. var.: P(loss to follow-up)	(1)	(2)	(3)	(4)
Treatment	-0.0120**	-0.00861	0.000318	
	(0.00596)	(0.00615)	(0.00162)	
Post			0.156***	0.152***
			(0.0196)	(0.0182)
Treatment x Post			0.00451	0.00440
			(0.00578)	(0.00581)
Observations	14,139	14,139	149,780	149,780
Adjusted R-squared	0.003	0.012	0.026	0.034
Number of patients	2,667	2,667	22,536	22,536
Mean dep. var. (control)	0.041	0.041	.007	.007
Month FE	Y	Y	Y	Y
District FE		Y		
Clinic controls		Y		
Clinic FE				Y

Notes: This table reports the effects of the intervention on a dummy whether the patient was $\geq$ 20-day delayed to a ART refill pick-up. Observation unit a visit v of patient p at clinic c in month t. Columns (1) - (2) include the newly enrolled patients (who enrolled after the introduction of the scheduling system and thus do not have pre-treatment observation). Basic controls for this subsample include clinics' characteristics (urban, number of patients in ART, HIV diagnostic capacity index, ANC readiness index, laboratory exams capacity, number of clinicians, hand wash infrastructure for patients). Columns (3) - (4) include older cohorts in which we progressively include fixed effects (clinic and patient). Standard errors in parentheses are clustered at the clinic level.

and could have had a significant impact on their treatment adherence. To investigate how the introduction of an appointment scheduling can represent a reverse back on their patient experience and affect their decision regarding treatment adherence, we present the results for the different cohorts in Figure 3.1. We see that the results on MPR found in Table 3.4 are mainly driven by the patients that started treatment in 2017 or prior to that, for whom the intervention caused an increase of 9.2 pp on the probability of properly possessing medication, which represents an increase of 12.2% in comparison to the control baseline mean. Moreover, we see that the effect on the probability of being delayed is significant for this group, with a decrease of 2.2pp on the probability of being delayed, representing a decrease of 20% on the baseline mean for patients in the control group.

Overall, we interpret the findings of the intervention on treatment adherence as the appointment scheduling positively affecting the effectiveness of the ART policy strategy to ensure patients have medication available, for all patients. However, the effect on complying with appointment dates and not being delayed is only significant for old cohorts, who have been on ART for over 3 years or more. To test whether the lack of effect on delays and loss to follow-up relates to patients' unchanged perceptions of quality of services provided, we complement the analysis on patients with data from the exit interviews with ANC patients. Table 3.6 presents the effect of the intervention on different dimensions of patient experience for the patients that visited the clinic after the intervention. Panel A presents results for all ANC patients where we see that the intervention had no effect on different dimensions on satisfaction with the experience of coming to the clinic that day.

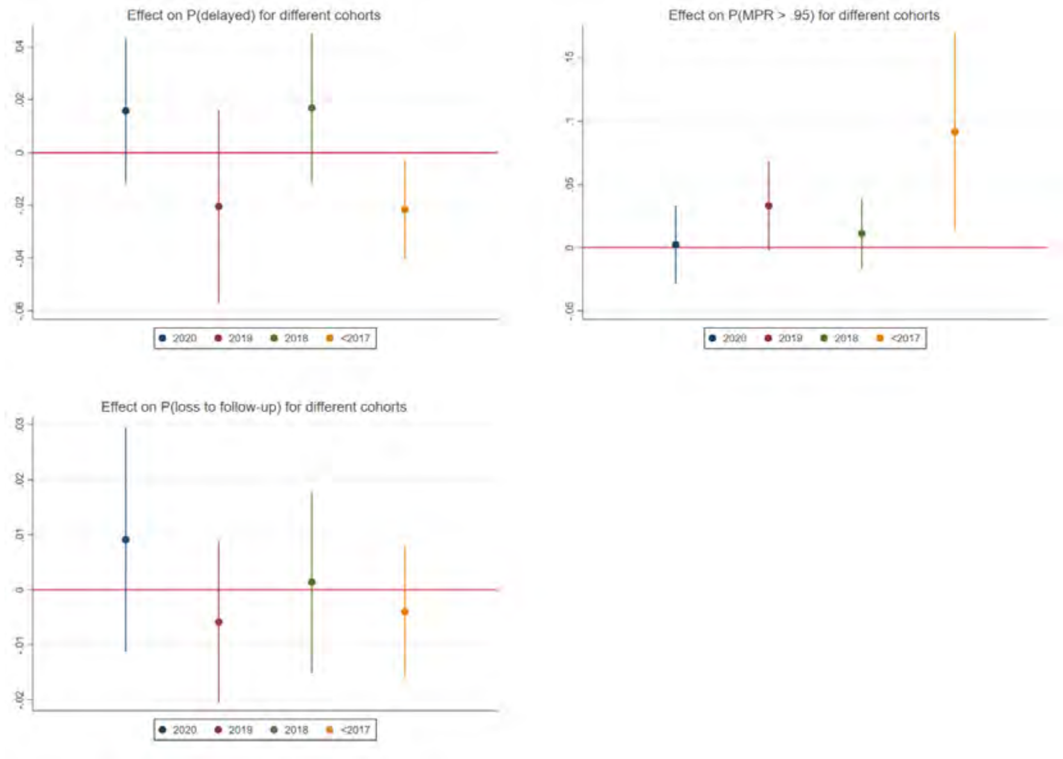


Figure 3.1: **Heterogeneous effects by cohort.**

Note: Effect of the intervention for different cohorts. All regressions include patient and clinic fixed effects, besides indicators for day of the week and month of the year. Standard errors clustered at the clinic level.

In order to check heterogeneities across patients who had interacted with the scheduling system before with those who had not yet, we then split the sample in Panel B and C between patients that came for their 1st visit and patients that came for follow-up visits. The 1st visit patients would not have experienced a visit in which the scheduling system was in place. The follow-up patients would have experienced few visits (on average 3.6 visits) in which their experience was affected by the intervention. Panel B shows that compared to patients in the control group, the intervention has not affected new patients' perception, which seems reasonable as they did not have a previous experience to compare their experience that day. In Panel C, follow-up patients report having experienced income loss on that day they came for their ANC visit in the treated clinics. Even though women who affirm to have any sort of income generating activity represent

Table 3.6: **Effect on patient experience**

	Satisfied waiting time	Satisfied waiting area	"Long waiting time is a challenge to attend ANC visit"	"Long waiting make it hard to choose between attend ANC or work"	Income loss
	(1)	(2)	(3)	(4)	(5)
			A. All patients		
Treatment	-0.0345	0.0748	-0.0267	-0.0601	0.0312
	(0.0382)	(0.0621)	(0.0549)	(0.0665)	(0.0241)
Observations	1,902	1,902	1,902	1,902	1,902
Adjusted R-squared	0.023	0.057	0.101	0.075	0.050
Mean dep var (control)	0.839	0.728	0.181	0.234	0.098
			B. 1st visit patients		
Treatment	0.0197	0.0938	-0.0499	-0.104	-0.00218
	(0.0567)	(0.0631)	(0.0630)	(0.0692)	(0.0561)
Observations	516	516	516	516	516
Adjusted R-squared	0.049	0.098	0.115	0.077	0.077
Mean dep var (control)	0.801	0.731	0.187	0.221	0.143
			C. Follow-up visits patients		
Treatment	-0.0516	0.0645	-0.0190	-0.0411	0.0438**
	(0.0348)	(0.0655)	(0.0568)	(0.0687)	(0.0215)
Observations	1,386	1,386	1,386	1,386	1,386
Adjusted R-squared	0.024	0.046	0.099	0.077	0.044
Mean dep var (control)	0.855	0.728	0.178	0.241	0.081

Notes: Each column reports the effect of the intervention for a different outcome from the ANC exit interview survey. Observation unit patient p from clinic c. Panel A refers to the full sample, Panel B to the subsample of patients coming for their first ANC visit on the day of the interview, and Panel C to patients coming for a follow-up ANC visit. Basic controls include patients' characteristics (age, education, marital status, number of kids, and number of kids under 5 in the household), and clinics' characteristics (urban, number of patients in ART, HIV diagnostic capacity index, ANC readiness index, laboratory exams capacity, number of clinicians, hand wash infrastructure for patients). Standard errors in parentheses are clustered at the clinic level.

a small sample (only 15.7% of follow-up patients), this evidence points in the opposite direction of the scheduling system allowing patients to organize their day not to miss a work day. We interpret this finding as the scheduling system increasing patient empowerment to complain about the system, as they update their prior about the health system responsiveness' to their needs.

3.6.2 Quality of care

To evaluate the effect of the intervention from the provider side, we use data from the exit interview to check whether the appointment scheduling could improve the probability of providers complying more with the clinical protocol. To capture providers' performance dimension, we focused on ANC visits, since for HIV patients clinical visits are considerably heterogeneous, depending on each patient's health status that day and making it hard to clearly create comparable measures on quality of the service provided.

Similarly to the analysis on patient experience, Table 3.7 show results for the full sample (column 1), and also split it into first visit patients vs. patients coming for follow-up visits. On average, for the full sample of ANC patients, the intervention had no effect on the share of procedures realized among the 21 procedures listed on the ANC guidelines from the Ministry. However, when we break it whether they came for their first visit or not, we see that there is a significant effect of 7.98 pp for patients on their first visit, which represents an increase of 16% on the control group mean.

Table 3.7: **Effect on ANC clinical procedures**

	All patients	1st visit	Follow-up visits
Dep Var: % procedures performed	(1)	(2)	(3)
Treatment	0.0304	0.0798***	0.0187
	(0.0219)	(0.0233)	(0.0200)
Observations	1,902	516	1,386
Adjusted R-squared	0.079	0.215	0.128
Clinic controls	Y	Y	Y
Patient controls	Y	Y	Y
Day-of-week FE	Y	Y	Y
Mean dep var (control)	.398	.506	.357

Notes: This table reports the effects of the intervention on the share of procedures performed the ANC visit. Observation unit patient p from clinic c. Column (1) refers to the full sample, column (2) to the subsample of patients coming for their first ANC visit on the day of the interview, and column (3) to patients coming for a follow-up ANC visit. Basic controls include patients' characteristics (age, education, marital status, number of kids, and number of kids under 5 in the household), and clinics' characteristics (urban, number of patients in ART, HIV diagnostic capacity index, ANC readiness index, laboratory exams capacity, number of clinicians, hand wash infrastructure for patients). All regressions include include day of the week fixed effects. Standard errors in parentheses are clustered at the clinic level.

To further investigate what kind of procedures explain the positive results of the intervention for the group of first visit patients, we split the 21 procedures we tracked in two groups. We separated the procedures that are exclusive to the first ANC visit (such as HIV and syphilis tests, provision of malaria net, collect urine and blood sample, calculate estimated delivery date and ask about past pregnancies), from any other procedure that could happen in a follow-up visit (such as blood pressure, malaria test, tetanus vaccine, folic acid pills, measure weight and uterine height, mention signs of pregnancy complications and nutrition advice, an discuss how to prepare for delivery). We then test how providers perform these clinical procedures for each patient group.

Figure 3.2 plots the coefficient θ of the specification on equation 3-4, but estimating separate regressions for different groups of procedures and type of patients as follows: 1) all procedures among the sample of all patients; 2) procedures exclusive to first ANC visit among patients coming for their first ANC visit; 3) procedures that typically happen in a follow-up visit among patients coming for a follow-up visit; and 4) procedures that typically happen in a follow-up visit among patients that came for their first ANC visit. We see that among all comparisons, the one that presents significant results is the procedures that would typically happen in a follow-up visit, but are carried out for the first-visit patients in the treated clinics. The intervention increased in 8.2 pp the share of "extra" procedures done during a first ANC visit, which represents an increase of 17.7% relative to the control mean.

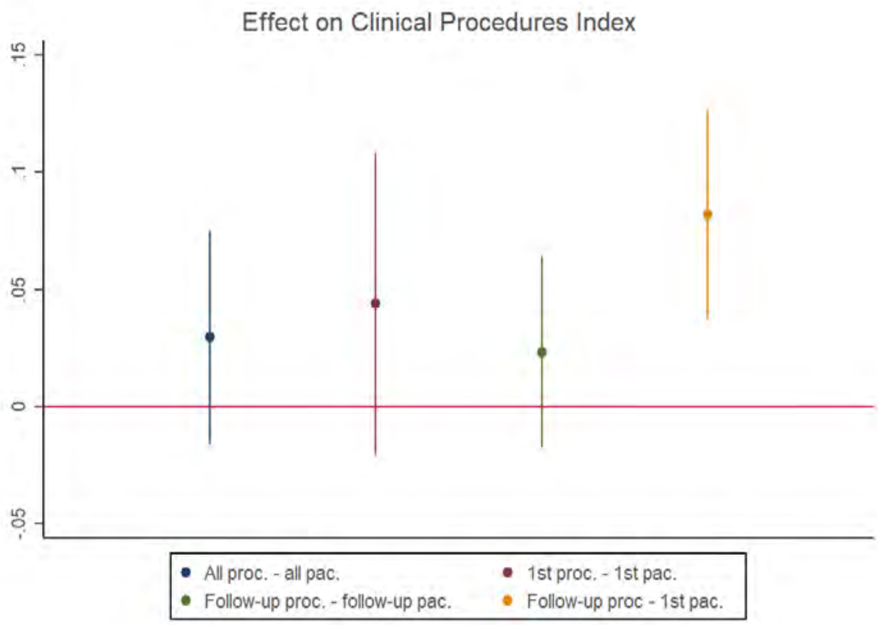


Figure 3.2: **Effect on quality of care.**

Note: Effect of the intervention on share of clinical procedures performed during ANC visit, for different group of procedures and type of patients. All regressions include patient and clinic controls and day of the week fixed effects . Standard errors clustered at the clinic level.

We hypothesize two possible explanations for this result. First, the scheduling system decreased the peak of patients in the first hours of the day. With follow-up patients scheduled to block-hours only after 10am, as described in detail in Section 3.3, providers could have had more time with each new patient, who would typically come in the first hours of the day as they were not introduced to the scheduling system yet. Second, besides extra time with the new coming patients, the disruption on overwhelming lines and disgruntled patients waiting outside the consultation room could decrease the over-stress providers usually mentioned prior to the intervention, which would positively affect their performance.

3.6.3 Implementation effectiveness

Finally, this section presents results on the implementation side. First, we show the effectiveness of the scheduling system in improving patient inflow along days of the week. As presented in Figure 3.4 in the Appendix, there is a peak of patient visits on Mondays and Fridays. Estimating equations similar to the ones presented in Figure 3.1, Figure 3.3 presents the effect of the intervention on a dummy for whether the pick-up happened on that day, for each day of the week. We see that the introduction of appointment scheduling was effective in reducing the probability that a patient would come for a pick-up on Monday, representing a decrease of 5.2% relative to the control baseline mean.

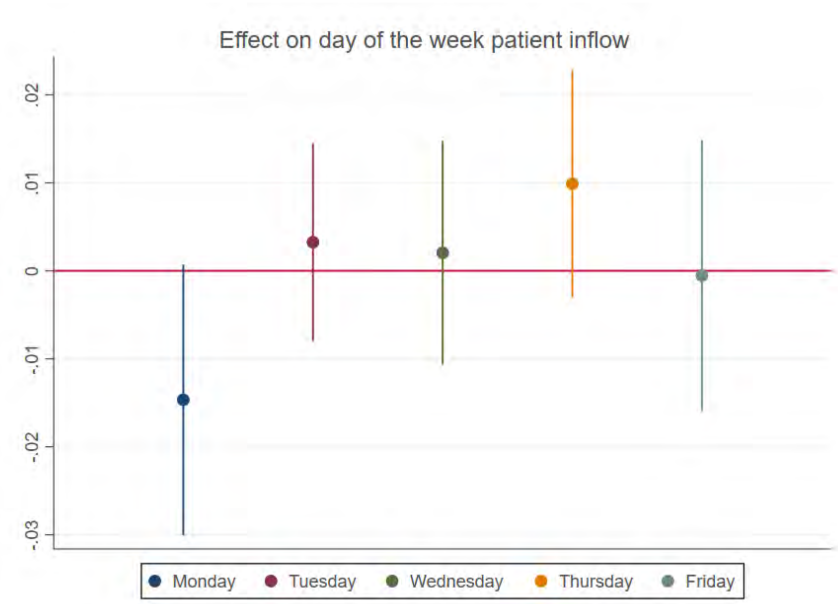


Figure 3.3: **Effect on the effectiveness of the intervention.**

Note: Effect of the intervention on dummy for visit happening at that week day. All regressions include patient and clinic fixed effects, besides indicators for month of the year. Standard errors clustered at the clinic level.

Second, considering this policy will scale-up to national-level, it is important to analyze whether the intervention presented unintended consequences, such as the scheduling system changing the pool of patients across clinics. As treated clinics become more attractive for patients due to lower waiting time and better quality of care, the scheduling system could have changed the total number of patients enrolled in those clinics. This composition effect of crowding in patients into treated clinics is tested by estimating the effect of the intervention on the total number of pick-up visits at the clinic level per week. Table 3.8 shows that there was no increase in the number of visits after the implementation of the scheduling system in the treated clinics. Previous evidence for the USA (McConnell et al. (2016)) shows that a patient's choice on which hospital to seek care is associated with the management score of the hospital. However, this result only appears conditional on patients having access to publicly reported performance measures. Considering the rural context of this study, we hypothesize that patients in the control group were potentially not aware of the introduction of the scheduling system in the treatment group.

Table 3.8: **Composition effect**

Dep var: Number of pick-ups per clinic per week	(1)	(2)	(3)
Treatment	16.71		
	(16.13)		
Post	47.29**	-0.217	-0.275
	(19.31)	(4.248)	(4.258)
Treatment x Post	2.728	5.259	5.322
	(5.210)	(3.846)	(3.851)
Observations	5,883	5,883	5,883
Adjusted R-squared	0.072	0.898	0.898
Number of facilities	80	80	80
Number of weeks	74	74	74
Mean dep var (control baseline)	103.7	103.7	103.7
Week FE	Y	Y	Y
Clinic FE		Y	Y
Month of the year FE			Y

Notes: This table reports the effect of the intervention on the number of pick-up visits. Observation unit clinic *c* at week *t*. Columns (1) - (3) progressively include fixed effects (clinic, week, and month of the year). Standard errors in parentheses are clustered at the clinic level.

3.7 Conclusion

This research significantly enhances the global knowledge about strategies to address the long-standing problem of long waiting time for care in public health clinics, which is quite common in Sub-Saharan Africa, but is also a challenge in high income countries, such as for the NHS in England (Giuntella et al. (2018)). The problem of mismanagement of patient inflows at public clinics goes well beyond the Mozambican context. From a cost-effectiveness viewpoint, the proposed intervention is very timely as countries in the developing world face the prospect of increased patient flows into already strained health systems. Particularly for HIV, the universal move towards a WHO-endorsed test-and-start strategy that requires starting all patients on treatment immediately after an HIV-positive diagnosis is already adding considerable pressure on Mozambique's health system. The findings from this research are therefore likely to have important policy implications for several other health systems in low and medium-income countries, as it is easily scalable and transferable to other areas of health care provision, requiring minimal staff training and limited financial resources.

More broadly, the experimental evidence on interventions specifically designed to affect the quality of health care without adding additional resources to health systems is growing (Björkman and Svensson (2010); Ashraf et al. (2020); Contreras-Loya et al. (2021); Dunsch et al. (2021)). Alternative approaches to improving the quality of health care have been tested previously, such as providing financial and non-financial incentives to providers, and involving community health workers in providing interventions that were previously only available in health clinics (Larson et al. (2018)). Evidence suggests these programs can have substantial positive impacts. However, they require increasing financing for health and often impose a significant administrative burden, which is challenging in most Sub-Saharan African countries. Instead, the intervention presented here can improve the allocation and productivity of the resources that are already available in the National Health System. Taking in consideration that the sector is systematically under-funded and dependent on external resources, the project has been pushed to the forefront of the government agenda as a critical and feasible reform.

From a public health perspective, low retention and adherence rates pose a significant threat to recent progress achieved in HIV testing and care over the last several years, and leaves Mozambique a long way from achieving the goals of the 90-90-90 strategy set by the Joint United Nations Programme on HIV/AIDS (UNAIDS): that 90% of all people infected with HIV are conscious of their status; that 90% of those that were diagnosed receive ART; and that 90% of people receiving treatment have suppressed their viral loads so that they are no longer infectious.

Loss of treatment can increase the spread of the disease and intermittent treatment can build drug resistance, reversing past gains.The lack of effect for newly enrolled patients points to the fact that improving patient experience when picking-up ART refills is not enough to affect their decision to stay on treatment. The requirements to keep on treatment at the beginning of ART might represent a big shock big, which might not be counterbalanced by marginal improvements in patient experience. However, for those patients who already present themselves as good compliers, improvements in the daily experience at the clinic can increase their treatment adherence.

Even though we find no significant effects of the intervention on patients' self-perception of patient experience, we find relevant positive results of the appointment scheduling on the quality of care provided. Our intervention proved to increase the quality of care in ANC for the new patients, who are the target group assigned by the Ministry to receive better care (in most clinics, first coming ANC patients are given priority in terms of queuing).

The lack of an appointment scheduling system relates to significant coordination failures that lead to the inefficient spacing of appointments. Existing international healthcare guidelines state that reasonable waiting time and prompt attention are key components of responsive health systems, with WHO calling for more patient-responsive high-quality care, as it affects patients' behavior and health outcomes (Larson et al. (2018)). Though short waiting time represents a key component of health system performance in several prominent guidelines, few resources exist that systematically describe interventions to reduce waiting time. We bring knowledge with practical guidance describing a simple and low-cost solution that can be used to decrease waiting time. Moreover, the scheduling system tested in this project is easily transferable to other areas of public service provision, requiring minimal staff training and limited financial resources.

The success of any policy change designed to increase service utilization and reach the goal of universal coverage of quality maternal health services may also require interventions that target the core components of the health system. Previous health system reforms such as the integration of HIV services into antenatal care, have resulted in longer waiting time and increased provider workloads. Improving patient flow through scheduling may be a useful area to trigger improvements in overall health system performance.

3.8 Appendix

3.8.1 Figures

Figure 3.4: **Distribution of ART pick-ups per weekday.**

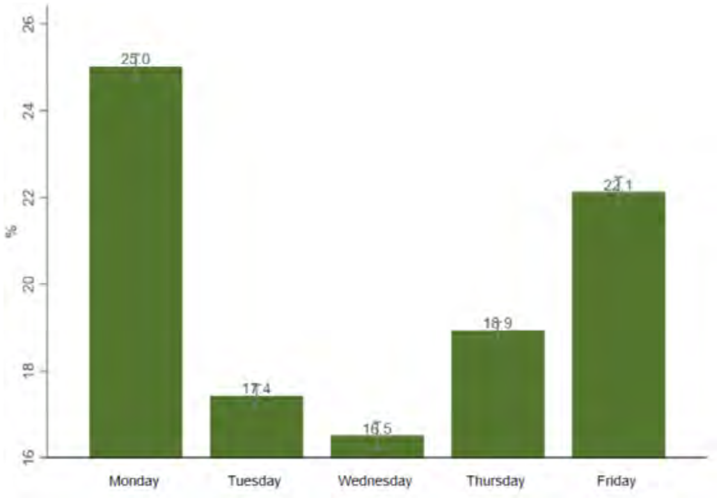


Figure 3.5: **Location of study clinics.**

Figure 3.6: **Timeline.**

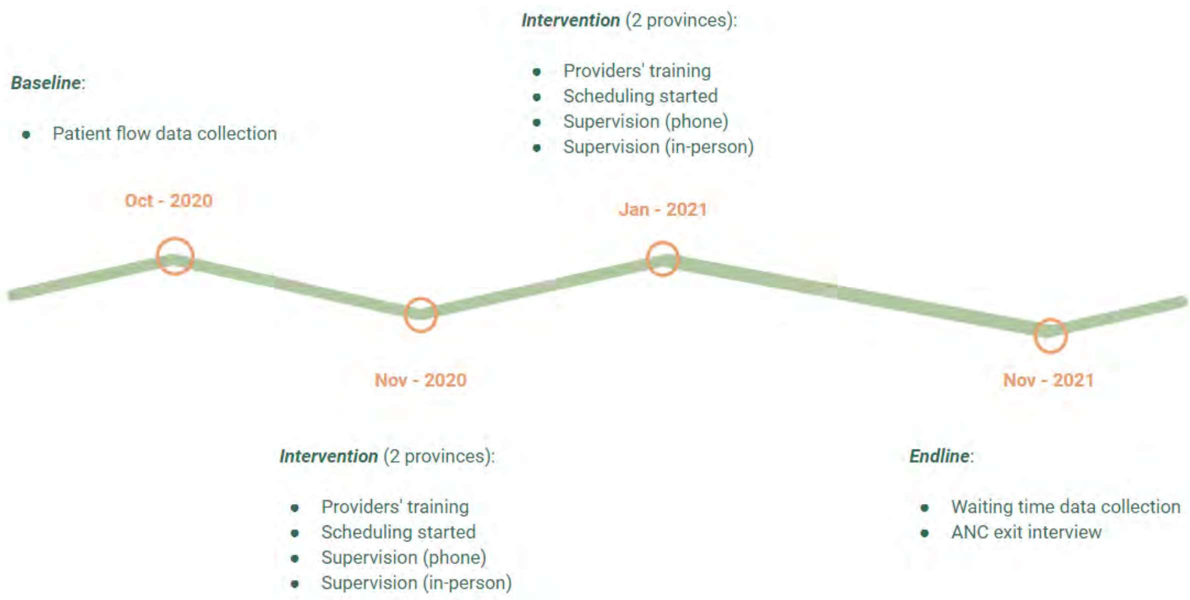


Figure 3.7: **Scheduling book for antenatal care patients.**

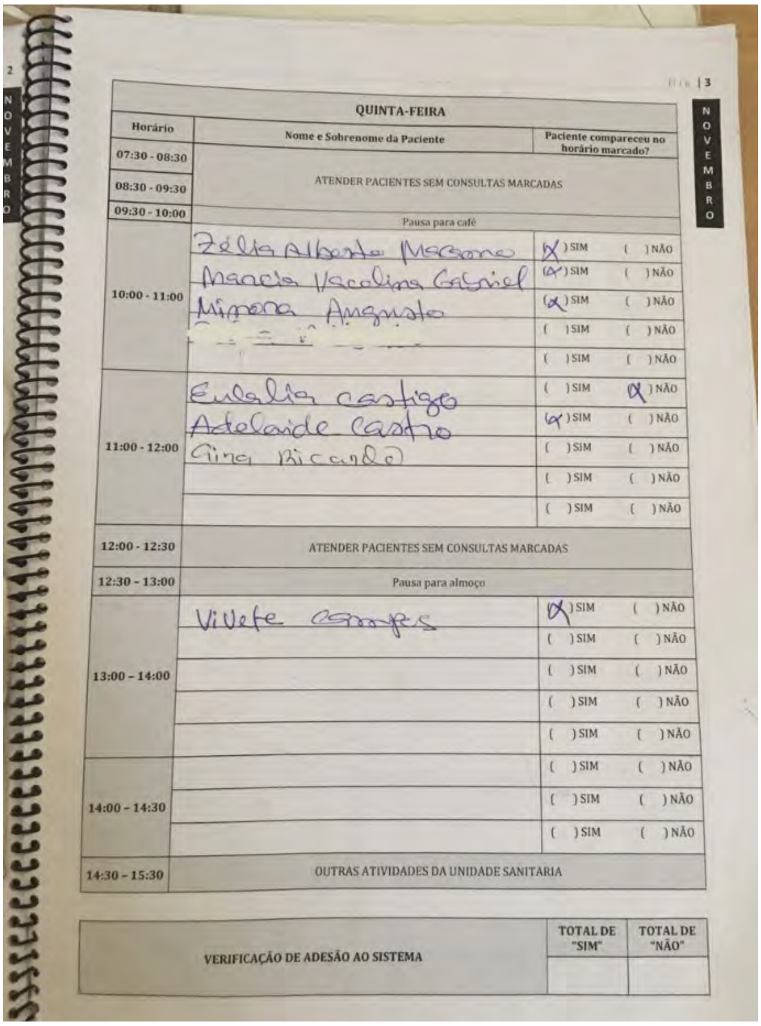


Figure 3.8: **Covid-19 and change in the ART regime.**

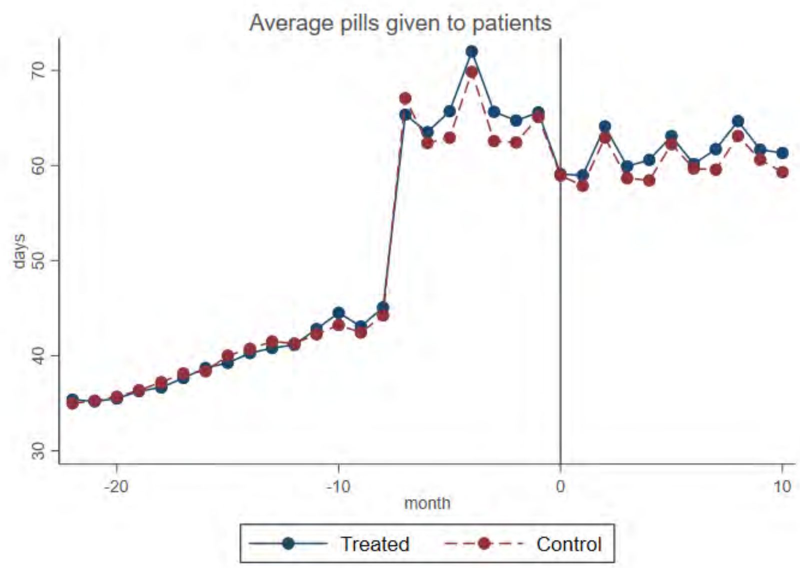


Figure 3.9: **Distribution of year of enrollment in ART treatment (all patients).**

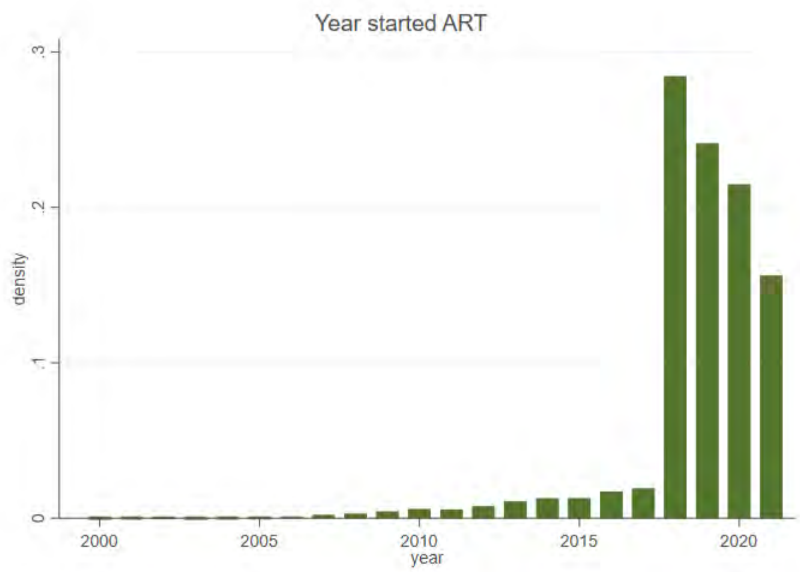
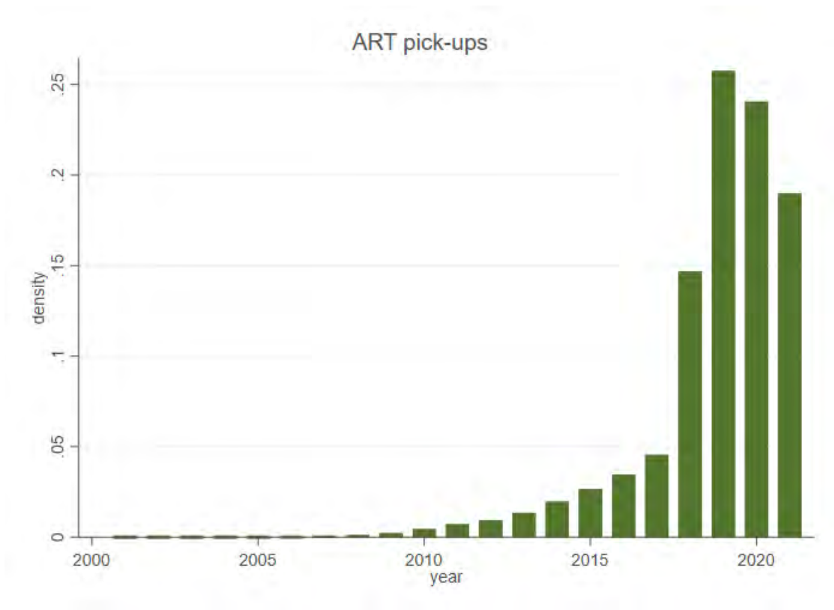


Figure 3.10: **Distribution of number of refill pick-up visits (all patients).**



3.8.2 Tables

Table 3.9: **List of clinical procedures according to Ministry's ANC guidelines**

1st ANC visit exclusive procedures	Follow-up ANC procedures
1. HIV test	1. Malaria test
2. Syphilis test	2. Malaria pills
3. Malaria net	3. Tetanus vac.
4. Urine sample	4. Blood pressure
5. Blood sample	5. Folic acid
6. Height	6. Uterine height
7. Calculated estimated delivery date	7. Weight
8. Ask past pregnancies	8. Examine belly
	9. Discussed place to delivery
	10. Discussed how to prepare for delivery
	11. Nutrition advice
	12. Mention signs of pregnancy complications
	13. Mention what to do in case of complications

3.8.3
Power calculation

We consider the statistical power for three key outcomes powered at 80% and with a significance threshold of 5%. Throughout we assume that all patients in clinics assigned to the treatment arm have their return care scheduled. We used administrative data from clinic records from 2016 to calculate a baseline measure of delays of 7 days or more in returning for ART of 72% and an intra cluster correlation of 0.07. Delays were measured by calculating the number of days between the scheduled clinical or ART pick-up visit, and the date of the next visit recorded in the administrative data. Delay is an indicator of whether each patient had any delay of 7 days in either a clinical visit or ART pick-up over a year-long period. Assuming we were able to observe the records of 500 unique patients per clinic who attended an HIV visit during the first two months of the intervention over a period of one year, we would be powered to detect a minimum reduction in adherence delays of 9 percentage points (12.5%).

3.8.4
Implementation details

Pilot. A pilot of this intervention was evaluated between September 2016 and July 2017 in four high-volume urban and peri-urban clinics located in different provinces in southern Mozambique, covering over 8,000 patients. This pilot focused on antenatal care provision only. Evidence from the pilot study showed that scheduling appointments reduced waiting times for antenatal care. Despite concerns that, even after scheduling, patients might continue to arrive early in the morning to guarantee a place in line, the study found that most patients arrived before or during their scheduled time, thus reducing an important coordination failure across patients and providers that rested on decades of social norms around queuing. Scheduling was also found to have increased the number of patients to have received complete (WHO- recommended four visits) antenatal care during pregnancy. This study was the first to provide evidence that appointment scheduling can increase service utilization, suggesting that poor patient experience may contribute to poor health outcomes by decreasing utilization.

Covid. Participating clinics implemented a scheduling system with the support of the training provided by the research team, and patients and providers in HIV clinics were also encouraged to follow the scheduling of appointments through IVR messaging. Three messages were deployed between February and June 2021.

Alongside the intervention, a wider programme of capacity-building has been deployed to ensure the sustainability of the intervention beyond the project timeline. Staff at both province and district level, who can in turn train nurses and clinicians at the selected clinics, have been trained by the research team and digital assets were developed that could be used in a potential scale up of the intervention. This "training of trainers" strategy ensures continued feasibility and quality. Community mobilization events have also been held to raise awareness among patients, while supervisory networks have also been established and trained among health authorities at the central, provincial, and district levels. This has been a considerable challenge to implement in times of COVID and has worked with varying degrees of success. This experience will also be procedurally assessed in the final report that will discuss fidelity to the implementation of the scheduling system.

4
Protests as Accountability Mechanism: Evidence of Brazil Mass Protests

Amanda de Albuquerque (PUC-Rio)
Helena Arruda (EAESP-FGV)
Claudio Ferraz (UBC and PUC-Rio)
Laura Karpuska (Insper)

Abstract

Despite the increasing occurrence of street protest, it is still unclear if they have been successful to work as an accountability mechanism. We propose a theory of protests as a Bayesian persuasion mechanism and we ask what are the conditions such that protests can be a successful tool for accountability. We think about accountability in two ways. First, we see accountability purely as persuasion, as incumbents responding to the demands from the street. Secondly, we think about accountability in the sense of citizens reelecting incumbents that are responsive to voters demands with higher probability. Our model shows that protests that do not have a clear demand – and so face a noisy communication channel, are not only less successful, but they can be ex-ante inefficient as persuasion mechanism. Interestingly, noisy protests help to separate politicians that deliver the demands from the street from the ones that did not deliver, improving electoral accountability. We take the model's findings to the data. We empirically analyse the effects of the large street protests that took place in Brazil in 2013 in both voters and federal legislators behavior. Using Twitter data, we compute a measure on how noisy protesters' demands were in each municipality. Consistent with the model, we find that noisier protests are less effective in persuading politicians to allocate resources to protests demands, showing there is empirical evidence that noisy protests are less effective as an accountability mechanism in the persuasion sense.

4.1
Introduction

Political protests have been a common mechanism for citizens to signal their preferences or simply to express their lack of satisfaction with the incumbent government. Ortiz, Burke, Berrada and Cortés (2013) report that the number of political protests has increased over time.[1] Despite this increase, it is still unclear if protests have been somehow successful. In fact, the literature indicates that protests vary in how effective they can be. From 843 protests studied in the 2013-2016 period in their study, only 37% of them achieved in some way their stated demands.[2]

Despite a burgeoning literature on what determines protests and how citizens coordinate to solve the collective action to mobilize, little is known about the effects of protests on politicians actions and electoral outcomes. In this paper we study the effects of the political protests that took place in Brazil in June 2013 to analyze the effects of these political phenomena in both politicians and voters. For over 2 weeks, more than 2.8 million people went out to the streets to demand changes in a huge range of areas, starting with the revocation of an increase in the bus fare, and going through education, health and prevention of corruption.

Given this political context, we test whether political protest can work as accountability mechanism in two ways. First, we see accountability purely as persuasion, with incumbents responding to the demands from the street. Elected politicians may act in divergence to the people's will because there is a conflict of interests - and voters are poorly informed of politicians actions (Ferraz and Finan (2008)), or because the politicians themselves are lacking information about voters preferences. The first studies on protests propose an information-driven model of the effectiveness of political activism and emphasize its role of revealing private information to the public at large and to policymakers (Lohmann (1993, 1994)).

Secondly, we think about accountability in the sense of electoral accountability, with citizens voting in incumbents that are responsive to voters demands. Institutions that perform audits and other types of checks and balances are important mechanisms that can complement electoral accountability by providing more information for voters to evaluate a politicians' performance. There is a vast literature on the impact of those formal mechanisms on electoral accountability, but less is known on political engagement by the civil society and, importantly, what are the political mechanisms

[1]Ortiz, Burke, Berrada and Cortés (2013) recorded 843 protests during the period of 2006-2013. The authors note a "steady increase in the overall number of protests every year, from 2006 (59 protests) to mid-2013 (112 protests events in only half a year)". A more updated list of protests and riots kept by Wikipedia indicates that, while the peak of protests and riots registered in the world happened in 2011, the average number of protests per year increased to 28 in the 2010's from 18 in the 2000's.

[2]For Ortiz, Burke, Berrada and Cortés (2013), an an achievement is "taken to be the set of direct-, mixed- and indirect-responses from targeted opponents or by society to a protest episode, responding in some measure to the grievances raised by protesters".

through which this type of civil engagement can work for accountability.[3]

Using data from federal legislators' performance, related to pork barrel (budget amendments allocation), legislative duty (proposal of bills) and rent-seeking behavior (presence in plenary), we explore variation on the share of the electorate of each legislator that went out to the streets to test whether political protests can make politicians' behavior more responsive to citizens' demands. Our results show that the average effect of the protest on legislators are null. With this result, we then explore whether the success of protests as an accountability mechanism is related to the quality of the messages voiced by protesters. We build a theoretical model to understand how protests that do not have a clear demand – and so face a noisy communication channel – would affect 1) legislators response to protest demands and 2) voters' decision to reward politicians that heard demands from the street.

To measure quality of the protests, we use Twitter data to measure how noisy was the messages sent out from protesters, in a sense of not asking for clear actions from politicians. Brazil 2013 protests are a particularly interesting case since protests started with a very clear demand, which was related to lower transportation fares in the main cities in Brazil. However, as protests evolved, social demands started to become more widespread, from the rejection of Brazil's hosting the World Cup and the Olimpic Games, to a general lack of satisfaction with incumbent politicians and even popular rejection to bills that were being discussed in the Congress that could limit the investigative power of the Prosecutor's Office (PEC 37/2013). We collected over 5,3 million tweets posted in June 2013 identified by the municipality where the user was posting it. With this database we created, for each municipality, a noise index – which accounted for the number of tweets related to protest that had no clear demand stated.

Using this index that measure how noisy the demands from the protests were, we re-estimate the effect of protests on legislators' performance. Our results show that protest are only effective in changing legislators' behavior after we account for the quality of it: without controlling for how noise the messages sent by protesters were, we do not find effect of street protests on legislators' actions. However, we only find relevant and significant effects for the pool of candidates who run for reelection, who indeed would be the ones facing reelection incentives (career concerns), the main source of accountability identified by the literature for Brazilian legis-

[3]For a more detailed discussion on this topic, refer to Khemani, Dal Bó, Ferraz, Finan, Stephenson Johnson, Odugbemi, Thapa and Abrahams (2016).

lators (Bertholini, Fajardo, de Faveri and Pereira (2013); Leoni, Pereira and Renno (2004)). Our results points that clear messages are more effective in persuading politicians to allocate resources to protests demands, showing that protests can an accountability mechanism in the persuasion sense under certain circumstances. At low levels of noise, protests led to an increase of 22.5% on their pork barrel performance relative to the pre-protest mean. We conclude from this exercise that protest may work as accountability exercise only if the messages sent by protesters are sharp and clear.

Considering that protesters' demands has not been completely considered in politicians' actions, we evaluate the second layer of protest as accountability mechanism. Using elecotral data from 2010 and 2014 election, we look for differential effects of voters who lived in a municipality which experienced a protest, and find that there is negative significant correlation on the share of votes that goes to an incumbent politician in the election after the protest. However, once we include legislators' performance in votes for the incumbents following the protest, we find that voters are not taking into account legislators' response to protests when taking their vote decision.

The political economy literature has focused mostly on the determinants of protests. Protests can be a mechanism that allows citizens to inform an incumbent government of their private preferences (Lohmann (1993), Lohmann (1994)). Citizens may also decide to go out on the streets to express their demand motivated by a sense of unfairness (Passarelli and Tabellini (2017)), motivated by the sense of belonging to a group of citizens (Barbera and Jackson (2016)), because they are unsatisfied with their income underperformance (Campante and Chor (2012)), or because there are no strong institutions through which citizens can participate in the political process (Machado, Scartascini and Tommasi (2011)). Moreover, part of the literature on protests has focused on the size of protests as a measure of their success (Battaglini (2016) and Correa (2020)), since size can improve information aggregation from heterogenous voters. For us, protests are taken as given. Our citizens are motivated because they want to signal their preferences to the incumbent and tilt the government's actions towards their preferred outcome. Our main contribution is discussing the quality of the messages coming from protesters, rather than the size of the protest.

With regard to the effects of political protests on politicians' behavior, a smaller piece of literature show that political protests can affect policymaking and voting behavior. For instance, there is evidence that the Tea Party Movement in the United States (Madestam, Shoag, Veuger and Yanagizawa-Drott (2013)) made incumbent representatives vote more conservatively.

Different than the american democracy, in which legislators represents and has a direct mapping with voters from a specific location (county), in the Brazilian case, legislators are elected on a proportional open-list scheme, in which legislative elections occur with various parties and candidates elected within multimember districts. Regarding the differences between these two systems, there is evidence that legislators elected by majoritarian rules behave more accordingly to their constituencies' will, being more accountable, while on the other hand representatives elected by proportional rules behave more as rent-seekers, since they are less accountable (Gagliarducci, Nannicini and Naticchioni (2011)). We contribute to this literature by including a quality dimension of the message transmitted by protests. For us, protests that has no clear demand will less likely be more persuasive to make legislators accountable.

Our paper adds strong support to the value of informal mechanisms of accountability, and we find results consistent with the political economy literature that examines the role of "social accountability" in promoting transparency and political efficiency. While our focus is on mass street protests, the mechanisms through which protests may work as accountability are all political. Therefore, we contribute to the discussion on what are the conditions such that citizens direct participation in democracies may be effective in improving accountability. How effective civil engagement can be, such as street protests, will depend on the capability of leaders to respond to citizens, as our model and empirical evidence suggests, and on other institutions that determine the political process in a country (Khemani, Dal Bó, Ferraz, Finan, Stephenson Johnson, Odugbemi, Thapa and Abrahams (2016), Grandvoinnet, Aslam and Raha (2015)).

Finally, a relevant contribution of our work is that we focus on quality of information delivered by protests. Both the theoretical and the empirical literature on protests tends to focus on the share of the population that went to protest as a measure of the "quality" of the demonstration. Although we agree this is certainly an important driver of protests working as an social accountability mechanism, our work focus on the quality of the information delivered by protesters and disentangle the pure occurrence of protests from the quality of these protest, allowing us to say something about effectiveness of protest as accountability mechanism.

The paper is organized as follows. Section 4.2 provides a brief background on Brazil's 2013 mass street protests. Section 4.3 presents the theoretical model of protests as Bayesian persuasion and its results. Section 4.4 describes the data used in the empirical analysis. Section 4.5 presents our empirical strategy, Section 4.6 presents the results and Section 4.7 concludes the paper. Moreover, section 4.3 presents the theoretical model of protests as Bayesian persuasion which completed and guided the empirical work.

4.2
Background - The 2013 Protests

Initiated mainly by the "Movimento Passe Livre" (MPL, Free Fare Movement), a social movement that advocates for free public transportation, the demonstrations were initially organized to protest against an increase in bus and metro fare in some Brazilian cities. The protests were violently repressed by the police in São Paulo, Brazil's largest city, and what seemed to be just another series of acts among several others organized by the MPL, took nationwide repercussion and protests spread throughout the country. Between June 17th and 30th, the movement had grown to become Brazil's largest protests since the 1992's against former President Fernando Collor de Mello.

More than 775 protests happened in 433 municipalities (around 7,8% of total number of municipalities), leading at least 2.8 million individuals to the streets from all over the country. Figure 4.26 depicts a map of the municipalities that had at least one protest. Although the protests did not occur uniformly across the territory, they took place in every state of the country. Table 4.7 in the Appendix shows the percentage of the population from each state that lives in a municipality that had a protest. Despite being concentrated in Southeast and South regions, the state less affected by the protests had 18% of its population experiencing a protest. We can see that there is a huge variability among the brazilian states in what refers to the occurrence of protests. Disregarding Distrito Federal (DF), that has just one municipality, citizens from the state of Rio de Janeiro (RJ) are the ones that experienced more protests: over 80% of the population live in a municipality that had a demonstration.

Besides the fact that these protests were the biggest ones over the last two decades, it is interesting to notice that the protesters, composed mainly by youngsters, had a wide agenda of demands. However, most of the demands refers to disappointment with the inadequate provision of public services and widespread corruption affecting most of Brazilian governmental institutions. Although the raise in the bus fares were revoked or postponed in several municipalities, the protests kept going for a few more days. We see in figure 4.27 that at the most intense day of the protests (June 20th) citizens were demonstrating in over 120 municipalities, taking more than 1.5 million people to the streets.

Most of the demands were directed to the executive branch (president Dilma Rousseff, governors and mayors) and just a couple of days after protesters have set fire in front of the Presidential Palace, the president made a public announcement of a wide set of proposed policies, contemplating themes such as public services, urban mobility, fiscal discipline and a political reform. However, there were also demands referring to the legislative competence. In Brasilia, the national capital, protesters decided to demonstrate in front of the National Congress and when the police could not hold them back anymore, they went up and took control over the rooftop of the Congress.

The demands related to the legislative branch include the revocation of a constitutional proposal that limited the power of prosecutors to conduct criminal investigations (PEC 37), the criminalization of all forms of corruption as heinous crimes, the end of the secret vote in Congress to expel a legislator, the destination of 10% of the Brazilian GDP to education and of petroleum royalties to education (75%) and Health (25%). There were also some themes that were not a consensus among the protesters, like the end of all taxes on public transport, the implementation of free public transportation to the students enrolled regularly, and the revocation of "Gay Cure" bill authorizing sexual orientation conversion therapy by psychologists.

4.3 Theoretical Model

4.3.1 Summary

In our theoretical model, protesters and incumbent may disagree on their preferred outcome for a public policy or a set of policies. A political protest is an information mechanism designed to persuade the incumbent government to deliver the protesters' preferred action. Formally, our model follows the Bayesian persuasion literature (Kamenica and Gentzkow (2011)) where a sender – the protesters, will design an information device that will produce a message that aims to tilt the receivers believes up to the point in which this is consistent with the receiver's prior. While protesters can design this information mechanism to maximize the chances of persuading the government, the delivered message can go trough a noise communication channel (Tsakas and Tsakas (2017)), misleading the government. A protest that has no single clear demand will be considered a noisy protest.

The model points that protests can increase accountability in the two ways mentioned above, but the impact of noise on accountability is not straightforward. First, protests improve accountability in the sense of persuasion by increasing the chances that the incumbent delivers the preferred action of the protesters. The noisier the protest, however, the lower the impact on the incumbents action. Importantly, if noise is "big enough", protests can be ex-ante inefficient as an accountability mechanism, since they won´t be able to tilt the incumbent´s actions towards the one preferred by voters above the threshold of 50%.

Secondly, protests can work also as electoral accountability. Going against the common wisdom, noisy protests may be better to help voters distinguish high and low quality politicians. By attending the demand from the street the incumbent government has higher chances of being reelected because it will be perceived as a high quality politician – and this will be increasing with noise. If the politician does not deliver the demands from the streets, it will be perceived as a low quality politician, facing lower chances of reelection – and this will be also increasing with noise. In other words, the greater the noise, the higher is the separation of types condition on the actions taken by politicians after protests.

4.3.1.1 Protests as Noisy Bayesian Persuasion

Our modeling strategy is to model protesters as information designers that want to persuade a benevolent, yet uninformed incumbent government, to take their preferred action. Therefore, protest is an information mechanism. While protest participants have room to design features of the production technology that will generate such information, they are not able to completely control the final result or even to completely manipulate the government to take their preferred action. This means that protests will generate messages that are *Bayes plausible* in the sense of Kamenica and Gentzkow (2011).[4]

Both protesters and the government share a common lack of information regarding a true state of the world that is relevant for the government's actions. Protests are taken as given and we abstract from explaining the emergence of protests. A key feature of our model is that governments differ on their capability of understanding the message designed by protesters. While high quality governments hear messages designed by protesters with

[4]In political terms, this also means we are thinking about protests in a democratic environment and not on protests that will lead to regime changes, as in the empirical work of Cantoni, Yang, Yuchtman and Jane Zhang (2019), for example.

no noise, low quality ones may observe a different message than the one that was actually transmitted. The noise that low quality governments may face is connected to the intrinsic quality of the protest itself.

In fact, when asking the question when, or if, protests are an efficient tool to persuade governments, it is also important to focus on the quality of the message that was transmitted by the protest. While some protests have a clear focus in terms of demand (costly public transportation or education, against police abuse or even against a reform of a public policy), other protests quickly expand to become a simple repudiation of the incumbent government or a general dissatisfaction with the *status quo*. Therefore, in our theoretical environment, a noisy protest is one such there is no specific clear demand or as so many demands that makes it harder for politicians to understand the demands from the street and respond accordingly.

4.3.1.2
Players, policy and state

There are two players in this economy, an incumbent government (G) and an interested group of protesters (P). There is an unknown state of the world $\omega \in \Omega = \{0, 1\}$. The incumbent is benevolent to the extend that she cares about policy $a \in A = \{0, 1\}$ that matches the state of the world. Therefore, her payoff depends on her action and on this unknown state of the world. An example of payoff function that satisfies this requirement would be $u_G = \mathbb{1}_{a=\omega}$. The incumbent has an unknown quality, $\tau \in \Gamma = \{L, H\}$. Her quality only matters for her capability of understanding the relevant information that will form her belief about the state of the world. High ability governments interpret signals about the state of the world without any noise, while low ability ones may interpret signals with noise. More details of this will be explained in the information structure part below. Protesters are self-motivated and only extract utility when $a = 1, \forall \omega \in \Omega$. One may think that $a = 0$ represents a pension reform to an overly benevolent pension system and $a = 1$ represents keeping the status quo. While the government would like reform the pension system ($a = 0$) if the state of the world is such that a reform would be better ($\omega = 0$), the government would like to keep the system as it is ($a = 1$) if the state of the world is such that no reform is better ($\omega = 1$). Protesters would always want the government to keep the system as it is, i.e., $a = 1$. Therefore, the payoff function of protesters can be given by $u_P = \mathbb{1}_{a=1}$.

The payoffs we present above are an extreme case of conflict of interests between government and protesters. The extreme case we study is the most interesting one for analysis, since it reveals results for the biggest disagreement that can exist between the two parts. We could follow a modeling strategy in which both players would care, to different extents, about the true state of the world and to some specific policy. This would only reduce the importance of protests as a persuasion mechanism and would not change qualitatively our theoretical findings.

4.3.1.3
Information structure

Our modeling strategy is to define protesters as information designers that aim to persuade the rational incumbent to take the protester's desired action, as in the Bayesian persuasion literature, following Kamenica and Gentzkow (2011). One may think that protesters would gather to decide how they will inform the government on which action to take. Protesters are farsighted and take into account how the government will react to the protest and how likely it will be for the government to take the desired action, $a = 1$. As information designers, protesters design a signal device that will deliver signals such that the chances the government will be persuaded are maximized. In other words, protesters will design the signal structure in such a way they can choose from the set of all possible posteriors the government can form after they observe the realization of the protest.

Therefore, a protest consists of a finite realization over the space S – that define all possible signal realizations, and a family of distributions $\{\pi(s|\omega)_{\omega\in\Omega}\}$ – that define the probability attached to each signal realization. Following Kamenica and Gentzkow (2011), we restrict our attention to a specific class of signals $s \in S$, the ones that are *straightforward*, i.e., $S \in A$. This means that that $s \in S$ can be reduced to an action recommendation to the incumbent.[5] Both government and protesters have a common prior $\mu_0 = \Pr(\omega = 1)$ and $\lambda_0 = \Pr(\tau = H)$.[6] In our example of binary states that follow with signals and types that are also binary, the information structure that will be designed can be represented by a pair of probabilities for $t \in \Gamma = \{H, L\}$:

[5]This is not without loss of generality in the environment where signals are noisy. A richer signal-space would be beneficial to protesters, as shown by Tsakas and Tsakas (2017). We abstract from this to keep the model tractable and easier to communicate with the empirical analysis performed later in the paper.

[6]The government also doesn't know her type. This is a common assumption in the literature to prevent another layer of strategic interaction between the government and the protesters.

	$\pi(s=0\|\omega,\tau=t)$	$\pi(s=1\|\omega,\tau=t)$
$\omega=0$	$1-q_0^t$	q_0^t
$\omega=1$	$1-q_1^t$	q_1^t

Table 4.1: Signal structure $\pi \in \Pi : (\Omega,\Gamma) \to \Delta(S)$.

From Table 4.1 we see that protesters want to maximize q_0^t and q_1^t, i.e., they want to maximize the chances that the protest signal will be such that it recommends the government to take action $a = 1$. The protesters cannot set $q_0^t = q_1^t = 1$ because that would not be Bayes plausible in the sense of Kamenica and Gentzkow (2011). This means that protesters cannot ignore the previous information that the government already has - her prior. This is clear in the solution for the optimization problem solved by protesters, shown in Appendix C

But not all governments are alike. Some high ability incumbents ($\tau = H$) may interpret with clarity the information received from the signal device of protests, while low ability types ($\tau = L$) may mistake the signal received. For the low ability case, we follow Tsakas and Tsakas (2017) adding noise to the classic Bayesian persuasion model. Differently from them, noise can only happen when the politician is low quality. In fact, the low type of government mistakes a signal $s = 1$ for one of $s = 0$ and a signal $s = 0$ for one of $s = 1$ with probability ϵ. We assume $\epsilon < \mu_0$ for consistency of results.

Therefore, a noisy signaling mechanism consists of a message from protesters $\pi \in \Pi : (\Omega,\Gamma) \to \Delta(S)$ optimal to the sender, and an exogenous noisy channel $p : (S,\Gamma) \to \Delta(S)$ that may distort the message that was produced by the protest. Thus, $p(s'|s,\omega)$ denotes the probability that the receiver observes s' when s has been realized by protesters. A signaling structure (π, p) induces a signal $\sigma : (\Omega,\Gamma) \to \Delta(S)$ such that

$$\sigma(s|\omega) = \sum_{t\in\Gamma}\sum_{i\in S} p(s|i,t)\pi(i|\omega,t) \tag{4-1}$$

The set of feasible signals is denoted by $\sum_p \subset \Pi$, for a given p. Each feasible signal $\sigma \in \sum_p$ induces a mapping from the state space $\omega \times \tau$ to $\Delta(B_p) \subset \Delta(S)$, with $B_p = \{p(.|s=0,t), p(.|s=1,t)\}$.We borrow from Tsakas and Tsakas (2017) an illustration of the set of feasible signals $\sum_p$ for our binary example:

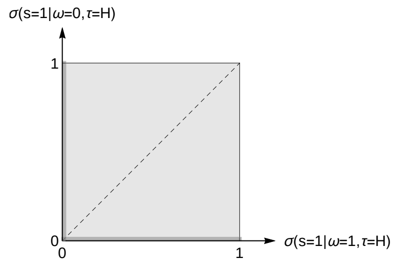


Figure 4.1: High quality government

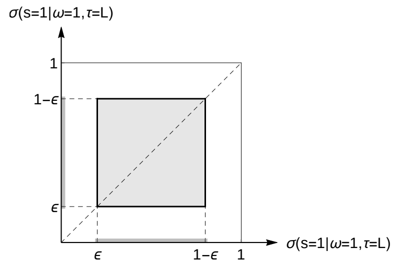


Figure 4.2: Low quality government.

Figure 4.3: The set of feasible signals $\sum_p$ for the binary channel p and for both high and low quality governments. We borrow the figure on the right from Tsakas and Tsakas (2017).

The figure above depicts the set of feasible signals for each type of government. On the left side of Figure 4.3, we show the the feasible message space of the high quality government, which is the entire message space. Each element of this space represents a probability attached to $s = 1$. The low quality government $\tau = L$ receives a signal from protesters with noise. This means that the message space that is feasible is the convex hull of $B_p = \{\epsilon, 1 - \epsilon\}$ where $\sigma(s = 1|\omega, \tau = L) = 1 - \epsilon$ if $\pi(s = 1|\omega, \tau = L) = 1$ and $\sigma(s = 1|\omega, \tau = L) = \epsilon$ if $\pi(s = 1|\omega, \tau = L) = 0$.

After the protesters have designed the signaling mechanism and given a type τ and a noise mechanism ϵ, the government of type τ will update her belief about the true state of the world. For each signal realization $s \in S \cap A$ there will be a posterior belief $\mu_s^\tau \in \Delta(\Omega)$, found by Bayes rule. For each $\omega \in \Omega$

$$\mu_s^\tau(\omega) = \frac{\sigma(s|\omega)\mu_0(\omega)}{\sum_{\omega' \in \Omega} \sigma(s|\omega')\mu_0(\omega')}$$

Following, we will denote $\mu_s^\tau(\omega = 1)$ simply as μ_s^τ for the sake of clearer notation. Each signal σ induces a two-dimensional profile of posteriors $(\mu_1^\tau(\omega), \mu_2^\tau(\omega)), \forall \tau \in \{H, L\}$ – since we are focusing on signals that are *straightforward*. Also, each posterior $\mu_s^\tau(\omega)$ happens, from an ex-ante perspective, with probability given by

$$\tau(\mu_s^\tau(\omega))) = \sigma(s|\omega)\mu_0(\omega)$$

An illustration of the probability trees that the protesters face is depicted in Figure 4.6 below.

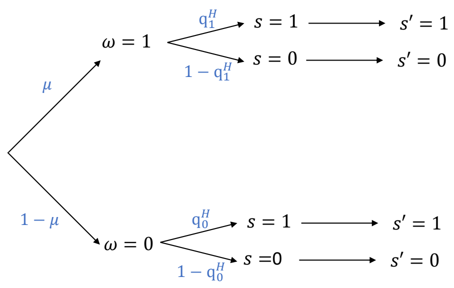


Figure 4.4: High quality government – probability λ_0

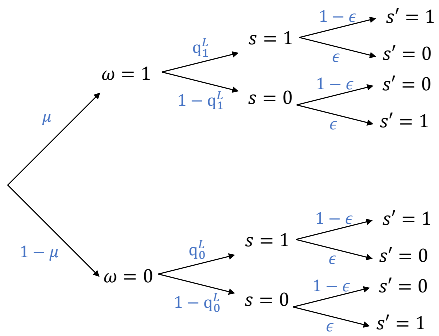


Figure 4.5: Low quality government – probability $1 - \lambda_0$

Figure 4.6: The noise structure depends on the quality of the government.

4.3.1.3
Protests as persuasion mechanism

Our benchmark case is the classic Bayesian persuasion model from Kamenica and Gentzkow (2011), which corresponds to the high type $\tau = H$ incumbent. Following their result, we find that protests are an effective persuasion tool for protesters. The addition of noise, however, makes protests a less efficient tool for the protesters.

Proposição 4.1 *The optimal signaling structure is given by:*

$$q_1^L = q_1^H = 1$$
$$q_0^L = \frac{\mu_0 - \epsilon}{(1-p)(1-2\epsilon)}$$
$$q_0^H = \frac{\mu_0}{1-\mu_0}$$

This signaling structure induces the following set of posteriors from the government:

$$\mu_1^L = \mu_1^H = \Pr(\omega = 1 | s' = 1) = 0.5$$
$$\mu_0^L = \Pr(\omega = 1 | s' = 0, \tau = L) = \frac{\epsilon \mu_0}{1 - 2(1-\epsilon)\mu_0}$$
$$\mu_0^H = \Pr(\omega = 1 | s' = 0, \tau = H) = 0$$

All the proofs can be found in the Appendix C. When the state is such that $\omega = 1$, there is no incentive for protesters to deliver any other action recommendation rather than $s = 1$. Therefore, $q_1^L = q_1^H = 1$. When the state is such that $\omega = 0$, protesters have an incentive to persuade until the government is indifferent, in expected terms, between choosing $a = 0$ or $a = 1$, which delivers $q_0^L = \frac{p-\epsilon}{(1-\mu_0)(1-2\epsilon)}$ and $q_0^H = \frac{\mu_0}{1-\mu_0}$. This signal message probabilities will induce posteriors.

The intuition for the result of Proposition 4.1 can be found below. If there are no protests, the probability that the government behaves accordingly to protesters interest, that is to take $a = 1$, is given by their prior probability μ_0 as shown in the dashed black line. When protests happen and all governments are high type ($\tau = H$) – meaning there is no noise in the communication channel, protesters are an effective persuasion tool, doubling the probability that the government delivers the preferred action of protesters – as shown in the garment solid line with circles. When all governments are of low type ($\tau = L$), protesters are less efficient. When all governments are high type ($\tau = H$), this probability can be reached from $\mu_0 > 0.25$ on – the intersection between the gray dashed line and the garment solid line with circles. However, when all governments are low type ($\tau = L$), this can only be achieved from the point $\mu_0 > 0.42$ on – the intersection between the gray dashed line and the blue solid line with squares. In this case, if protesters face a noisy communication channel, unless we start from a point in which governments are pretty inclined to already deliver $a = 1$, protesters are less likely to be an effective persuasion mechanism.

It is ex-ante optimal for the government to choose $a = 1$ if and only if her posterior $\mu_s(\omega) \geq 0.5$. While $\mu_1(1) = 0.5$, it is easily shown that $\mu_0(1) < 0.5$ for $\epsilon < 0.5$ – a reasonable assumption.[7]

In fact, we could think that protesters would like to persuade the government until, from an ex-ante perspective, she is indifferent between taking $a = 1$ or $a = 0$, which would be at the point in which $\Pr(a = 1|s) = 0.5$ – represented by the gray dashed line above. We formalize how noise can reduce the efficiency of protesters as a persuasion mechanism for different levels of λ_0, the prior probability that the government is high type.

Corolário 4.2 *The optimal signaling structure induces a set of posteriors and the following action behavior from the government:*

$$\Pr(a = 1|s' = 1) = 2\mu_0 \left(1 - \epsilon(1 - \lambda_0)\right)$$
$$\Pr(a = 1|s' = 0) = 0$$

Since the government will choose $a = 1$ if and only if her posterior is higher than 0.5 and this happens only when $s' = 1$, the probability that the government will choose $a = 1$ is the same as the one that $s' = 1$ is delivered. Therefore, we can think about the effectiveness of protests is measured by the probability that protesters persuade the government, i.e., the probability that the government chooses $a = 1$, or that $s' = 1$ is delivered. This can happen when protesters intended to say that $s = 1$ and there was no noise in the communication channel, or when protesters said $s = 0$ but there was noise in the communication. How the signaling mechanism will impact this effectiveness will depend on (i) the size of the noise, ϵ; and (ii) on the mass of governments that are low type, λ_0.

[7]One could think that $\epsilon \geq 0.5$. This would mean the mistake is so significant that there are higher chances that the message sent by protesters will be misunderstood by the government. If that is common knowledge – as it is the case in our environment, the protesters would take into account and would choose a signal device that would take this into account, swapping the optimal signaling structure we saw above.

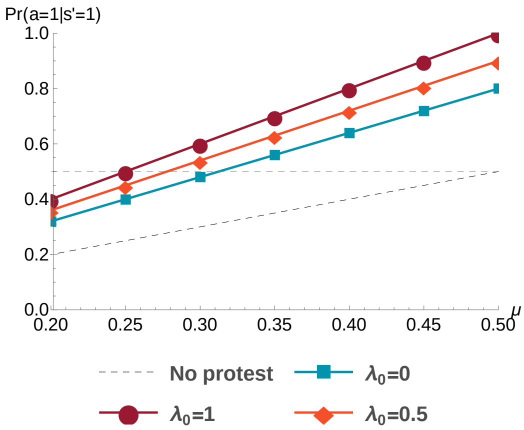


Figure 4.7: Efficiency of protests for μ_0 and $\epsilon = 0.1$.

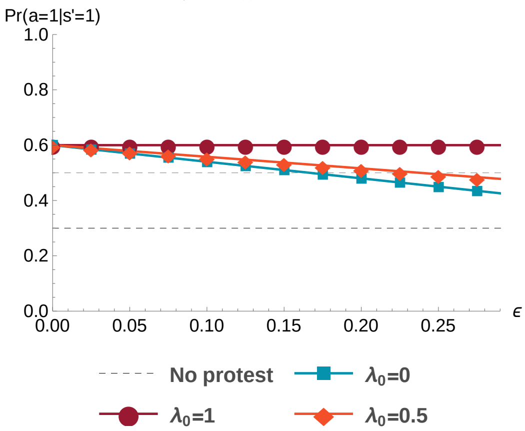


Figure 4.8: Efficiency of protests for ϵ_0 and $\mu_0 = 0.3$.

Figure 4.9: How protests are efficient depend on initial prior and noise size.

From the right plot depicted in Figure 4.9, we can see that the probability that the protest is successful - in the sense of increasing the chances that the government takes the preferred action from protesters which is $a = 1$, is decreasing with the size of the noise ϵ and increasing with the probability that the government is high type λ_0, an intuitive result. Since our measure of ex-ante successful is such that the probability that the government takes the preferred actions of protesters $a = 1$ at least with probability $\frac{1}{2}$, we plot below the whole parameter space of ϵ and λ_0 such that protests are ex-ante successful:

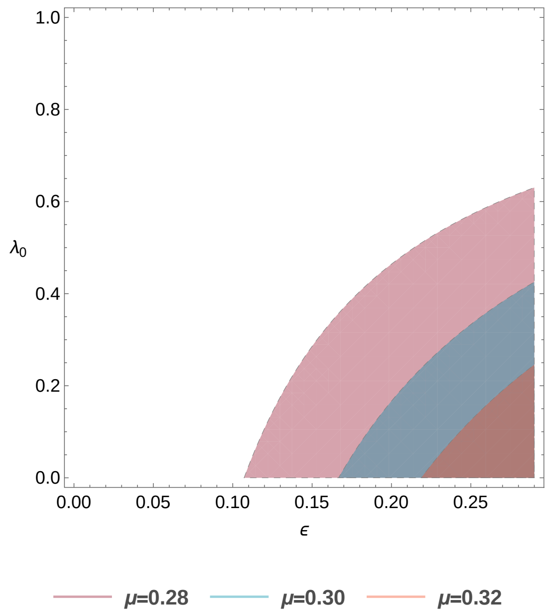


Figure 4.10: Efficiency of protests for pairs of ϵ and λ_0 and for selected priors μ_0.

4.3.1.3
Persuasion, anti-establishment bias and accountability

So far in our analysis we have asked how protests could be a useful persuasion tool. We have seen that there are higher chances of success the less noisy protests are. Now, we focus on how protests can change the perception of the electorate regarding the quality of the government. In order to do that, we have added a third player to this game, a citizen (C) that wants a high quality government and that shares the common priors μ_0 and λ_0. The citizen observes the action a of the incumbent and updates her prior belief on the quality of the government λ_0. If the posterior probability that the incumbent is high quality ($\lambda_1 = \Pr(\tau = H|a)$) is higher than the probability from an opponent from the common pool of candidates – that are high quality with probability λ_0 – the incumbent is reelected. Otherwise, the incumbent is replaced.

Corolário 4.3 *The updated belief of the citizen after observing the action of the government a is given by:*

$$\Pr(\tau = H|a = 1) = \frac{\lambda_0}{1 - \epsilon(1 - \lambda_0)}$$
$$\Pr(\tau = H|a = 0) = \frac{(1 - 2\mu_0)\lambda_0}{1 - 2(1 - \epsilon(1 - \lambda_0))\mu_0}$$

The ex-ante posterior equals the prior, i.e.

$$\lambda_1 = \Pr(\tau = H|a = 1)\Pr(a = 1) + \Pr(\tau = H|a = 0)\Pr(a = 0) = \lambda_0$$

The result still holds ex-post if there is no noise in the communication channel, $\lambda_1 = \lambda_0$. *When there is noise, however,* $\lambda_1 > \lambda_0$ *if* $a = 1$ *– and the incumbent is reelected, and* $\lambda_1 < \lambda_0$ *if* $a = 0$ *– and the incumbent is replaced.*

The intuition from Corollary 4.3 can be better given in the set of Figures 4.13 and 4.16. In the absence of noise, $\epsilon = 0$, regardless of the action a taken by the government, $\lambda_1 = \lambda_0$, as we can see by the initial point of the garment line with circles and the blue line with squares in both plots on Figure 4.13. When noise increases, the perception that the government is high quality $\tau = H$ increases if $a = 1$ and decreases if $a = 0$. This shows that, conditioning on the action taken by the government, the citizen will update her believes on the quality of the government in different ways. Noisy protests, therefore, can improve separation of low and high quality politicians conditioning on their actions after the protest.

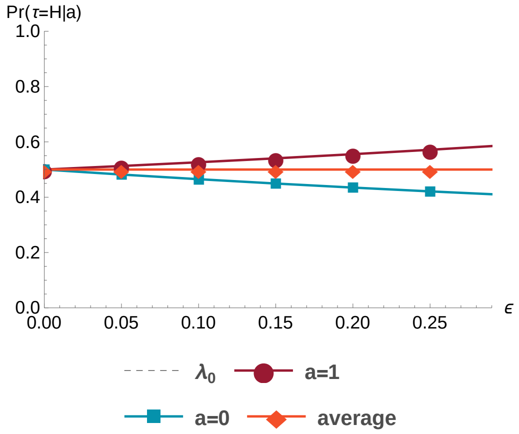


Figure 4.11: λ_1 for $\mu_0 = 0.3$ and $\lambda_0 = 0.5$.

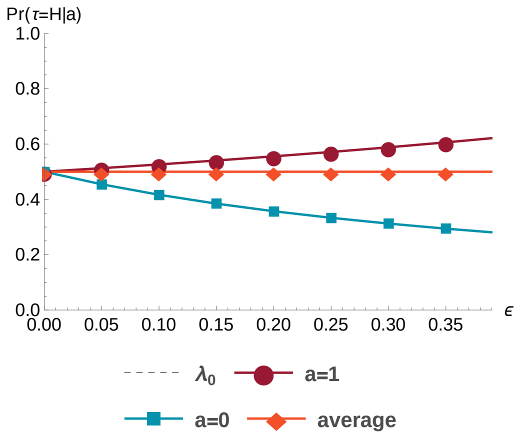


Figure 4.12: λ_1 for $\mu_0 = 0.4$ and $\lambda_0 = 0.5$.

Figure 4.13: Efficiency of protests to separate low and high quality politicians depends on initial prior and noise size.

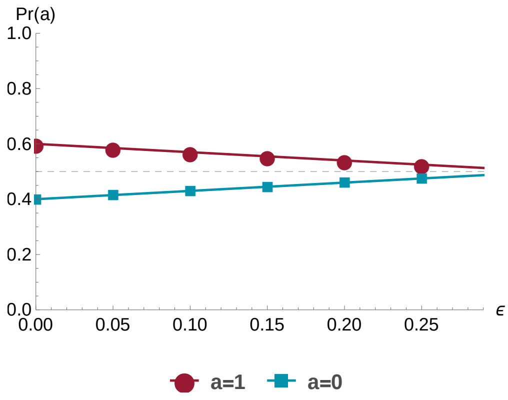


Figure 4.14: $\Pr(s')$ for $\mu_0 = 0.3$ and $\lambda_0 = 0.5$.

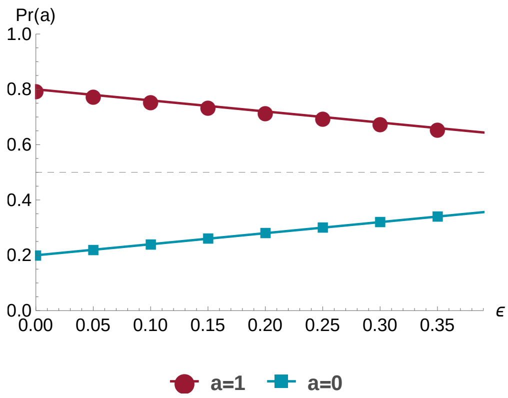


Figure 4.15: $\Pr(s')$ for $\mu_0 = 0.4$ and $\lambda_0 = 0.5$.

Figure 4.16: Probability that each signal is delivered.

In the empirical section, we focus on how the level of noisy in protests impacts accountability. We characterize accountability in two ways. First, we define accountability as having politicians answering to protests demands, since we assume protests work as a channel for voters to voice their preferences. In the model, we measure this as the probability incumbents will deliver $a = 1$, the preferred action of protesters. In the data, our proxy for this will be the category of bills signed by deputies and a reallocation of pork barrel spending between municipalities. We also focus on the second dimension of accountability which is to have voters rewarding incumbents that delivered the demands from protests with reelection. In the model, this was measured by the ex-post probability of a high type politician to be reelected given the action taken by the incumbent, $\Pr(\tau = H|a)$. In the data, we study how the vote share of deputies is impacted by noise in protests – controlling for deputies actions in Congress.

4.4 Data

1. Protest occurrence. we use information collected by a Brazilian news website, G1, which is one of the biggest news site in the country. Few days after a police brutality at a protest in São Paulo, the website created a special session to cover issues related to protests that started taking place all over the country. The data compiled at the website contains information on whether a municipality had a protest or not, how many people attended it according to police estimates and how many days with protests a municipality had during our period of interest. The website covered the protests that happened between June 17th and June 30th.

Although it is relevant to know not only if there was a protest but the intensity of it, in terms of percentage of the population that participated in it, we use a binary variable reflecting whether there was at least one protest at the municipality instead of using the number of protesters. The reason is lack of precision on data about the intensity, since the protest attendance was measured by different sources, usually local police departments, and the access to the methodologies used to compute how many people showed up in each protest is limited. Thus, our analysis will be based on protest incidence, rather than protest intensity.

2. Tweets. We constructed a dataset of tweets to capture how noisy the protests were. We collected over 5.3 million tweets for all municipalities that had an active place id in Twitter platform between June 1st - 30th, 2013 (4,086 municipalities). Since the Twitter API requires a keyword for the query to be made, to construct a random sample of tweets for each municipality we set the query on Twitter Academic platform to search for tweets that had any vowels (a, e, i, o, u).[8] In this way, we aimed not to bias our sample by collecting tweets that were related to protests. This allowed us to collect a random general sample of tweets for all municipalities, with which we created a measure of the twitter activity related to protest on each municipality.

To identify the tweets that were related to protest in this random sample of tweets, we looked for keywords such as: *Movimento Passe Livre, "não é só por 20 centavos", "o gigante acordou", "vem pra rua", protesto, manifestação, democracia, governo, prefeito, deputado, senardor, vereador, Congresso Nacional, Senado* and *eleição*. The full list of keywords used in our query can be seen in Table 4.8 in the Appendix. To get to this list of words, we constructed a pre-test sample of tweets by querying for tweets that had the word "protest"

[8]We have collected tweets following a 10% of the population rule to not bias our sample.

or "manifestation" during the days that most cities registered protests (June 17th). Indeed, some of those words became famous hashtags at the time of protests, such as "vem para a rua" (come out to the street) or "o gigante acordou" (the giant has awaken).

Figure 4.17 illustrate how we used our random sample of tweets, showing also evidence that Twitter activity regarding tweets with our selected protest words peaked during the week the G1 dataset registered occurrence of protests.

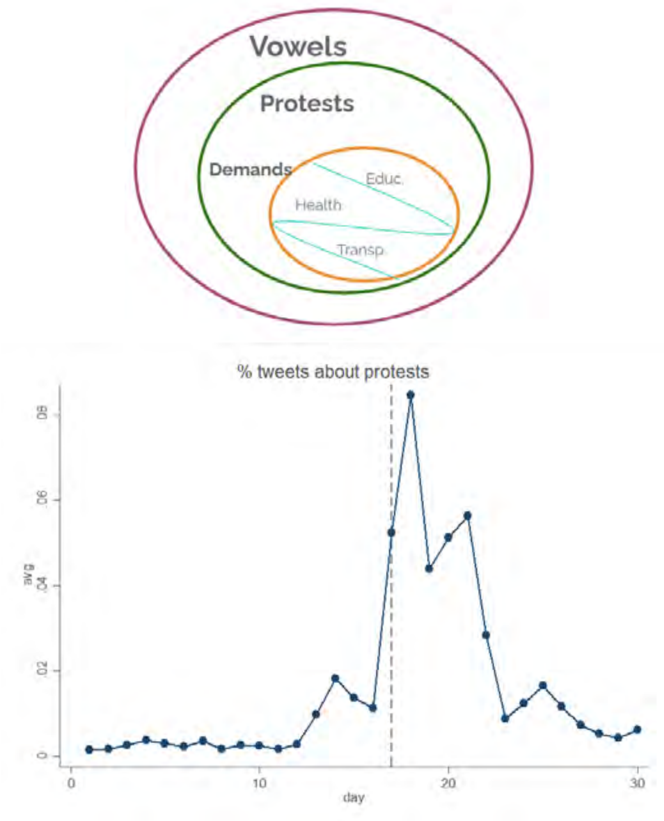


Figure 4.17: **Set of tweets and Protest activity on Twitter during June 2013.**

Among the tweets identified as related to protest, we then proceed to identify the tweets that had clear demands from the ones that were pure noise. To do that, we once again used our pre-test sample of protest tweets and were able to defined 5 demand categories: transportation, education, health, corruption, and security. A list of words on each category can be found on Table 4.8 in the Appendix. Having classified all protest tweets into whether or not they presented any demand, we get to our measure of noise at each municipality, which we use as a proxy for quality of protest, further explained in Section 4.5.

$$Noise\ Index_m = \frac{\sum_i 1_{No\ Demand_{i,m}}}{\sum_i 1_{Protest\ Tweets_{i,m}}} \tag{4-2}$$

3. Legislators' behaviour. we extracted information on three different performance variables: presence in plenary sessions and proposed bills (from the Chamber of Deputies' website), and data on the legislators' pork barrel spending (*"emendas parlamentares´´* or federal budget amendments in a free translation) (from the Federal Senate's website). We have data on 642 legislators that had a seat between 2011-2014, but we restrict our analysis to the 513 legislators who exercised their mandate during the protests' period. First, to analyze pork barrel spending, we collected data on the federal budget amendments from 2011 to 2013, using the share of the total amount of these amendments made by each legislator that relates to the protesters' demands. To classify an amendment as related to protests, we analyzed which ministry was assigned as the responsible for implementing the amendment. Amendments assigned to the Ministry of Health, of Education, of Transports, and of Cities were classified as related to the protests. Table 4.2 shows that on average, 17.8% of all individual amendments were related to the protesters' demands.

Furthermore, the main goal of the protesters was to get changes in substantial matters, such as the creation of new bills, like the one that reserves 10% of the GDP to education, and the repeal of laws, like PEC 37 discussed earlier. Given this context, besides using the total number of bills proposed by each legislator by quarter, we also look at the amount of these bills that relates to the protesters' demands and use a dummy whether the legislator proposed one. To classify a proposal of bill as related to protests, we identified for which commission in the Chamber of Deputies the proposal was assigned. If it was assigned to the Commission of Education, of Social Security, of Urban Development, and of Public Security, we classified it as a proposal related to protests. Between February 2011 and September 2014, legislators proposed 8.151 bills: 949 (12%) related to health, 319 (4%) to education, and 437 (5%) to urban development or public security.

Finally, we look at the frequency of presence of the legislator in all the plenary sessions by week. The period considered February 2013 to December 2013.[9] Table 4.2 presents the summary statistics of all variables,

[9]Although we have information from the beginning of the legislature, there were a change in the rules of the Chamber in October 2012, by which presence in plenary were mandatory from Tuesday till Thursday, instead of from Monday till Friday. This might have changed the dynamics of presence rate and, thus, we consider the legislative year of

where we see that the mean of the presence rate is 0.84.

Table 4.2: **Summary Statistics**

Variables	N	mean	sd
Legislators' characteristics			
Protest Exposure Index	513	0.469	0.280
Noise Exposure Index	513	0.894	0.104
Run for reelection	513	0.713	0.452
Electorate's characteristics			
Urban (%)	513	0.817	0.127
Internet penetration (%)	513	0.267	0.128
Literate (%)	513	0.885	0.067
Legislators' performance - baseline			
% budget amend. related to protests by year	579	0.178	0.210
Dummy bill related to protests' demands by quarter	4,236	0.103	0.303
Presence rate by week	9,646	0.840	0.285
Municipalities that had protest' characteristics			
Noise index	384	0.930	.105
Incumbent's vote share	29,446	1.086	5.42

Notes: Data on legislators were taken from TSE, Chamber of Deputies and Federal Senate websites. *Protest Exposure* is an index reflecting the percentage of the legislator's electorate that lives in a municipality that had a demonstration: the higher the index, more exposure to the protests the legislator had. *Noise Exposure* is an index that refers to the share of tweets related to protest at each municipality that present no clear demand. Municipal and Electorate's characteristics use data from the 2010 census and from TSE.

4. Electoral outcomes. we use data from the Superior Electoral Court (Tribunal Superior Eleitoral, TSE), which is the highest judicial body of the Brazilian electoral system, responsible for organizing and publicizing information relative to elections. From this database, we constructed two panels. First, we have constructed a panel of the legislators' vote share in each municipality in 2010 and 2014 elections. That is, we look at the vote share a legislator obtained in a municipality with respect to the total votes

2013

of the municipality.[10]

5. Controls. To test for heterogeneity on protests' effects, we use mainly data from 2010 census. Access to Internet refers to the share of households in a municipality with at least one computer with access to Internet. Education level uses information on the share of citizens with at least 10 years of age that are literate. We also use data from IDEB and IDSUS, which are indexes constructed to test quality of public education and health systems.

4.5 Empirical Strategy

1. Protests and the Accountability of Legislators. We start our empirical analysis focusing on the impact of protests on legislators' actions. Taking into account that rational politicians expect that street protests would be translated into dissatisfaction also during the elections, whereby voters would punish politicians that did not respond to their demands, we look at data from the Chamber of Deputies to measure whether legislators were acting accordingly or not to protests' demands.

We argue that legislators more or less exposed to protest would respond differently to protests and explore variation in how much each legislator was affected by the protests. We construct an index for each legislator that measures protest exposure taking into account the vote distribution she received in the previous elections.[11] The index was created according to the following equation, which in words represents the share of the legislator's electorate that lives in a municipality that had at least one protest in June 2013:

$$\text{Protest Exposure Index}_d = \sum_{1}^{M} Vote\ share_{md}.\mathbb{1}_{protest_m} \tag{4-3}$$

where $\mathbb{1}_{protest}$ is an indicator function whether municipality m had at least one protest; $share_{md}$ is the weight giving to each municipality, referring to the vote share coming from municipality m in the total votes to legislator d; and M refers to all municipalities of the state she was running for.

Legislators have incentives to act accordingly to meet their electorates' expectations. Using the variation in the legislators' share of voters that live in a municipality that had a protest, which is exogenous to protests from the

[10]We use this variable instead of using the vote share relative to the total votes of the legislator, since the variation in the treatment is at the municipal level.

[11]Exposure here does not refer to the share of a legislator's electorate that protested. As pointed before, information on the number of protesters is not reliable, and, thus, we use a dummy to indicate the municipalities that had at least one protest.

legislator standpoint, the index captures the influence of the protests over the legislators. Thus, to estimate the effect of the protests on legislators we begin by estimating the following OLS specification:

$$Performance_{dt} = \theta Post_t \times Protest\ Exposure\ Index_d + \alpha_d + \gamma_t + \varepsilon_{dt} \quad (4\text{-}4)$$

where $Performance_{dt}$ refers to one of the three performance outcomes, $Post_t$ is a dummy equal to 1 if period t is after the first week of protests, and $Protest\ Exposure\ Index_d$ is the variable capturing protest exposure for legislator d. Furthermore, α_d controls for legislators' time-invariant characteristics and γ_t controls for time fixed effects, and ε_{dt} is a random error term for the legislator d at period t. In all regressions, standard errors are clustered at the legislator level. Figure 4.19 plots the distribution of $Protest\ Exposure\ Index_d$ for the pool of the 513 legislators we have in our sample.

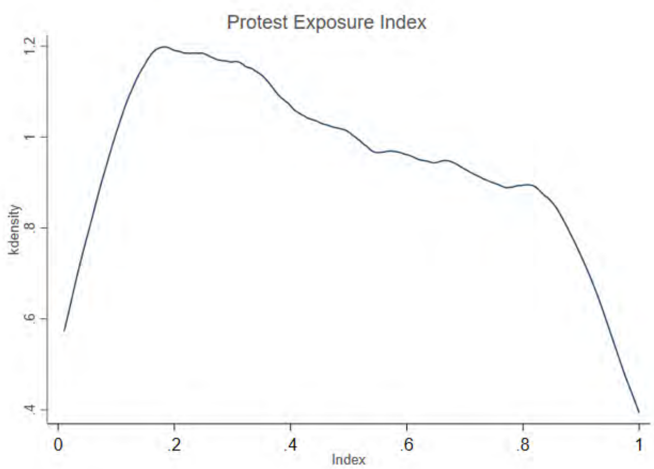


Figure 4.18: Distribution of *Protest Exposure Index*

Our identification strategy relies on the fact that since legislators were elected, they have been taking into account their electorate's preferences. In this sense, our index is exogenous conditional on past behavior, since legislators were not expecting protests to happen in June 2013. After the protests, then, the only reason why a legislator behaves differently conditional on his protest exposure index is because she responds to protests. Thus, this equation identifies whether the protests affected the legislators' behavior by the estimation of θ. If after the protests there was a difference in the behavior of those legislators whose electorate protested more, that is, if θ is statistically significant, then we can conclude that politicians responded to political protests.

With regard to $Performance_{dt}$, first, we look at pork barrel spending. In Brazil, the federal government has the prerogative to elaborate the annual budget proposal and legislators are allowed to amend the budget bill and propose individual amendments that transfer funds – which normally favor their electoral strongholds (Leoni, Pereira and Renno (2004)). They can propose a limited number of amendments, that can go up to a total of R$ 15 million per year (nearly US$5.8 million).[12] Congress only authorizes the budget. It is the federal government, however, who decides if and when to disburse the funds. In this regard, we look at data on the federal budget amendments proposed by each legislator – considering that looking at the amendments that were actually implemented by the Executive could bias the analysis. The idea is that legislators might have used these amendments as political tools to please voters from municipalities that had protests.

Although there is evidence that there is no direct link between pork and electoral success, Samuels (2002) shows that instead of trading pork for votes, Brazilian legislators trade pork for money, what then affects their electoral prospects. Albeit the link is indirect, we can still expect legislators to use pork and barrel to respond to protesters' demands. Firpo, Ponczek and Sanfelice (2015) find that politicians tend to favor municipalities that represents a bigger share of the votes obtained by politicians. Also, they provide evidence that voters support candidates who have brought resources to their localities, what explains why should legislators use pork barrel to fulfill protesters' demands. Moreover, delivering what voters want is the key accountability as persuasion outcome in our theoretical model. It seems that, even if indirectly, pork barrel spending would be a good proxy for this.

Second, we look to a variable related to the legislative duty of proposing bills, using the share *t* of these bills that relates to the protesters' demands. Third, we look at the frequency of presence of the legislator in all the plenary sessions by week. Following Nannicini, Stella, Tabellini and Troiano (2013), we use this variable to measure rent-seeking behavior. Legislators receive a salary and what it is minimally expected from them is participation in the parliamentary debate so as to contribute to the legislative procedure of elaborating relevant laws. Otherwise, if they are not contributing to the legislative activities, albeit being paid by society, then they are allocating their time in other personal activities that might be not related to a legisla-

[12]These values are from the period of analysis, 2013-2014. The rules for pork barrel spending have changed in 2021, increasing the amount of spending that can be redirected to it. The name of the legislator that will receive the fund is mandatory anymore, since the transfer can be made from the legislator responsible for proposing the Budget, which reduced transparency and accountability in Brazil. This does not impact our analysis, however.

tor's duty. The period considered February 2013 to December 2013[13].

Due to the different nature of the three dimensions of legislators' performance, t will refers to different time periods depending on the variable used as dependent variable. For presence in plenary rate, we aggregated data weekly, for the federal budget amendments we use data annually and for the proposed bills we did it quarterly. This is due to the difference response time a legislator can have relating to these different variables. Changing their behavior with respect to attend a plenary session is much less demanding than elaborating a new bill.

It is important to highlight that even if we estimate a statistically significant coefficient of $Post_t$, we can not conclude from it that the protests were a relevant factor for altering the legislators' behavior. That is, the legislators' electorate protested all at the same time and we can not disentangle the effects of the protests from other events that occurred after June 2013 and that might have affected all legislators similarly, likewise the 2014 elections. The identification strategy relies on the hypothesis that a legislator responds differently according to a higher or lower level of protest exposition. This limits our findings if, instead of responding accordingly to their electorate, all legislators responded similarly regardless of the behavior of their electorate.

Finally, although the comparison between legislators more or less exposed to protests identifies the average impact of protests on performance outcomes, it does not capture the fact that these effects might depend on legislators' characteristics. For instance, some literature argues that legislators behave accordingly either to maximize the chances they have to be reelected, as there are no term limits for legislative positions in Brazil, or to maximize the chances when running for higher positions (Leoni, Pereira and Renno (2004); Gagliarducci, Nannicini and Naticchioni (2011); Pereira, Hungria, Franchini, Kaschuk, de Oliveira Chueire, Campo and Torres (2007)). To test whether there is such differential effect, we estimate equation 4-4 splitting our legislators sample between those who would run in the 2014 election (that took place in October 2014, 1.25 year after the protests) from those would not.

2. Quality of protests. Complementing recent research that uses Twitter data to classify messages and relate it to political outcomes (Fujiwara

[13]Although we have information from the beginning of the legislature, there were a change in the rules of the Chamber in October 2012, by which presence in plenary were mandatory from Tuesday till Thursday, instead of from Monday till Friday. This might have changed the dynamics of presence rate and, thus, we consider the legislative year of 2013

et al. (2022), to incorporate a dimension on quality of the protest in the accountability effectiveness analysis of protests, we then include information on how noisy the messages from the streets were, including the $Noise\ Index_m$ for each municipality in our analysis. That is, to disentangle the effect of *protest exposure* from how the noise in the messages sent by protesters (measured by the share of protest tweets with no clear demands), we create the following index for each legislator:

$$\text{Noise Exposure Index}_d = \sum_{1}^{M} Vote\ share\ protest_{md}.Noise\ Index_m \qquad (4\text{-}5)$$

where $Vote\ share\ protest_{md}$ refers to the vote share legislator d received from municipality m among the pool of municipalities where there were at least one protest. This index capture the lack of clarity on the messages sent by the electorate that experienced a protest to each legislator. Table 4.2 present the distribution of the noise, in which we see it is skewed to the right, as most of the tweets represent pure noise in the sense of not presenting any clear demand to politicians. Figure 4.19 plots the distribution of $Noise\ Exposure\ Index_d$ for the pool of the 513 legislators we have in our sample. With a right-skewed shape, we see that most of the messages directed to legislators were noisy.

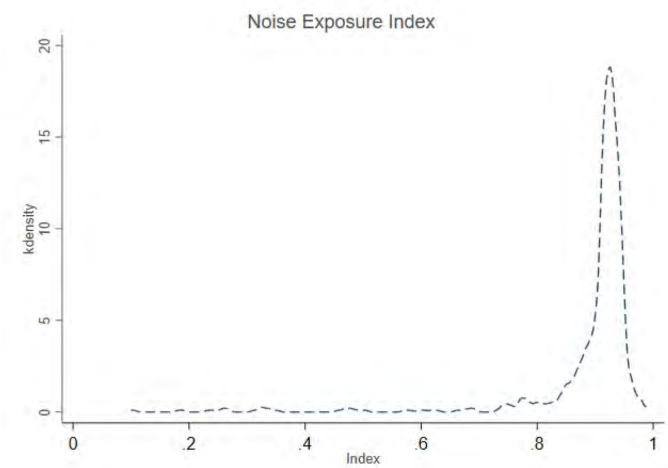


Figure 4.19: Distribution of $Noise\ Exposure\ Index_d$

With this index, we then test the response of legislators to protests, conditional on the quality of the message transmitted by protests, estimating the following equation:

$$
\begin{aligned}
Performance_{dt} = & \, \theta Post_t \times Protest\ Exposure\ Index_d & \text{(4-6)}\\
& + \beta Post_t \times Noise\ Exposure\ Index_d & \text{(4-7)}\\
& + \delta Post_t \times Protest\ Exposure\ Index_d \times Noise\ Exposure\ Index_d & \text{(4-8)}\\
& + \alpha_d + \gamma_t + \varepsilon_{dt} & \text{(4-9)}
\end{aligned}
$$

where all variables are as in equation 4-4. δ is the coefficient of interest, and captures how the noise of the messages coming from her electorate interplay with the effect of protest exposure.

3. Protests and Electoral Accountability. We follow to the second layer of accountability, the electoral accountability. We use data from the elections to test whether, in the sample of municipalities where there was a protest, those legislators who decided to run for reelection who responded more positively to protests were rewarded in the 2014 elections. We construct a balanced painel and estimate the following equation:

$$
Vote\ Share_{dmt} = \theta Post_t \times Performance_d + \alpha_{dm} + \gamma_t + \varepsilon_{dmt} \qquad \text{(4-10)}
$$

where $Vote\ Share_{dmt}$ refers to the share of votes that went to legislator d relative to the total votes of municipality m. $Performance_d$ refers to the legislators' actions analyzed in Equation 4-4. More precisely, we calculate the mean in the period post protest of presence rate and in share of federal budget amendments related to protests, and create a dummy whether the legislator proposed a bill related to protesters' demands after the protests. Considering the panel we have, we include α_{dm} which refer to legislator-municipality fixed-effect. We weight the observations by the number of voters who participated in the 2014 elections, to take into account that we aggregate individual voting behavior by municipalities and we aim to give higher weight in the estimation to those municipalities with more voters.

Different than the previous estimation of protests effects on legislators' behavior, in which we have exogenous variation coming from combining the timing of the protests with different protest exposure levels for each legislator, Equation 4-10 do not present casual evidence. As this analysis is done only in municipalities where there were a protest and the protest time shock is equal to all municipalities, these results can only be interpreted as correlations. That is, we can not clean our results from cofounders that could potentially affect the occurrence of the protest and voters' decisions in 2014 elections.

Through the estimation of θ, we can test whether voters considered incumbents' actions when they voted in the 2014 elections. We hypothesize that the underlying mechanism for this effect is that a lack of response on legislators' behavior after the protests shifted the electorate toward more gripped voters (Bidner and Francois (2013)), which ultimately changed their political behavior.

Finally, our theoretical model indicates that protests themselves do not impact electoral outcomes, but noise protests help voters to separate high type from low type politicians by observing who acted accordingly to voters demand and so, reelecting with higher chances this politician. To estimate the effect of noise protests on votes behavior, we estimate the following OLS for the same sample of municipalities where there was a protest:

$$Vote\ Share_{dmt} = \theta Post_t \times Performance_d \quad (4\text{-}11)$$
$$+\beta Post_t \times Noise\ Index_m \quad (4\text{-}12)$$
$$+\delta Post_t \times Performance_d \times Noise\ Index_m \quad (4\text{-}13)$$
$$+\alpha_{dm} + \gamma_t + \varepsilon_{dmt} \quad (4\text{-}14)$$

where $Noise\ Index_m$ refers to the share of tweets with no clear demands at municipality m. Through this equation, we test the hypothesis that the quality of the protest (more vs. less noise) would support voters to reward the legislators that perform more accordingly to protests demands, or punish those one that did not. Conditional on the noise of the protest at each municipality, the coefficient θ captures whether voters in each municipality are punishing or not incumbents. The coefficient δ tell us whether this rewarding-punish effect depends on the quality of the protest.

4.6 Results

4.6.1 Protests and Legislators' Accountability

We begin by presenting estimates of the effect of the level of protest exposure experienced by each legislator – captured by the *Protest Exposure Index*, on our three performance outcomes. Table 4.3 presents the results from estimating Equation 4-4 and 4-6. The results in columns (1), (3) and (5) show that there is no effect of protest exposure on legislators' performance: regardless of the share of the electorate that lived in a place with protests, legislators do not change their pork barrel strategy, bills proposal and presence in plenary to respond to protesters demands.

However, the figure changes once we account for the quality of the protest. Columns (2), (4) and (6) include our noise exposure index in the estimation. Columns (2) and (6) show that, for budget amendments and presence rate, once we account for the quality of the protest, protests seem to positively affect legislators' behavior. Even more, the negative sign on the coefficient of the triple interaction goes in the direction that there is a interplay between noise exposure and protest exposure, with more noise decreasing the persuasion effect of protests on legislators' behavior.

Table 4.3: **Effect of protests on legislators' behavior**

	% budgt. amend.		Dummy bill rel. prot.		Presence rate	
	(1)	(2)	(3)	(4)	(5)	(6)
Post x Protest Exposure	-0.00871	0.691*	0.0263	-0.582	-0.0152	0.219**
	(0.0421)	(0.414)	(0.0292)	(0.373)	(0.0144)	(0.0863)
Post x Noise		0.165		-0.221		0.0915*
		(0.129)		(0.173)		(0.0545)
Post x Protest Exposure x Noise		-0.754		0.664		-0.257***
		(0.468)		(0.404)		(0.0962)
Observations	901	901	6,698	6,698	21,767	21,767
Adjusted R-squared	0.553	0.553	0.116	0.117	0.226	0.226
Number of periods	3 years	3 years	14 quarters	14 quarters	43 weeks	43 weeks
Number of legislators	322	322	513	513	513	513
Mean Dep. Var. pre-protest	0.178	0.178	0.103	0.103	0.840	0.840
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Legislator FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the effects of the protests on legislators' performance. Observation unit is performance variable of legislator d at time t. Each column presents the result of an OLS regression where the dependent variable is listed in the column. Column 1 is at the week level, column 2 at the year level and columns 3 and 4 at the quarter level. *Post* is a dummy indicating periods after the protests and *Protest Exposure* is an index reflecting the percentage of the legislator's electorate that lives in a municipality that had a demonstration: the higher the index, more exposure to the protests the legislator had. All regressions include time and legislator fixed-effects. Standard errors are clustered by legislator and displayed in brackets.

To check the significance of these estimates considering we have a triple interaction with two continuous variables, Figure 4.22 plots the marginal effect of protest exposure, for five different noise exposure levels (respectively, values of the 10th, 25th, 50th, 75th, and 90th percentiles of *Noise Exposure Index* distribution), considering 95% confidence intervals. We see that although the marginal effect of protest exposure is decreasing on the noise exposure index, those estimate are not statistically significant.

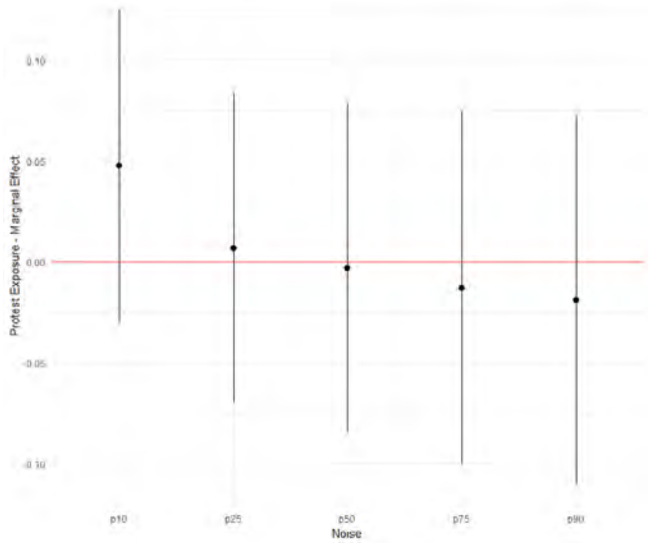


Figure 4.20: % budget amendments

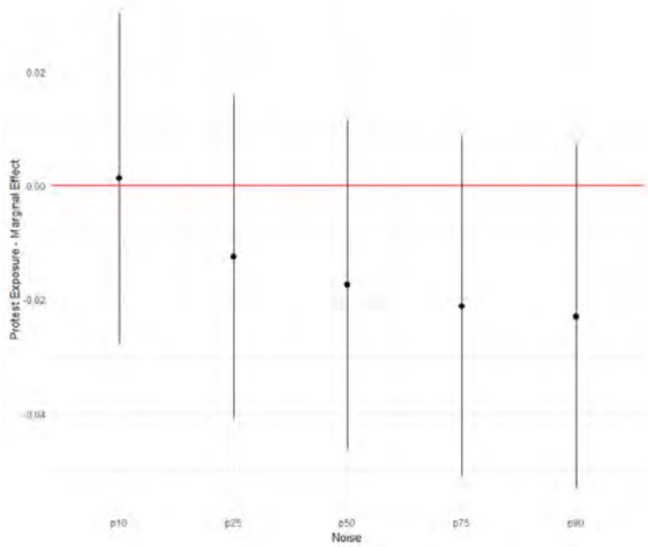


Figure 4.21: Presence rate

Figure 4.22: Marginal effect of *Protest Exposure Index* for $Post = 1$ and different levels of *Noise Exposure Index*. CI at 95%.

We then look on the how reelection incentives work when legislators are exposed to protest. Table 4.4 presents the result of the same specification presented in 4-6, but splitting the sample between legislators that decided to run for reelection in 2014 (N = 366) and those that did not (N = 147).[14] We see in columns (1) and (5) that the previous results for the full sample were mainly driven by the pool of legislators that decided to run reelection.

[14]Estimates of Equation 4-4 (without the inclusion of *Noise Exposure Index*) can be found at Table 4.9 in the Appendix.

Table 4.4: **Effect of protests on legislators' behavior - reelection incentives**

	% budgt. amend.		Dummy bill rel. prot.		Presence rate	
	reelection=1	reelection=0	reelection=1	reelection=0	reelection=1	reelection=0
	(1)	(2)	(3)	(4)	(5)	(6)
Post x Protest Exposure	0.856*	-1.303	-0.578	-0.602	0.279**	0.370
	(0.453)	(1.525)	(0.518)	(0.447)	(0.111)	(0.263)
Post x Noise	0.137	-0.116	-0.195	-0.280*	0.170**	0.0534
	(0.171)	(0.318)	(0.278)	(0.158)	(0.0719)	(0.0936)
Post x Protest Exposure x Noise	-0.898*	1.301	0.634	0.742	-0.319***	-0.433
	(0.519)	(1.648)	(0.562)	(0.475)	(0.123)	(0.290)
Observations	658	243	4,879	1,819	15,635	6,132
Adjusted R-squared	0.575	0.482	0.117	0.112	0.218	0.229
Mean Dep. Var. pre-protest	0.18	0.18	0.18	0.18	0.18	0.18
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Legislator FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the effects of the protests on legislators' performance. Observation unit is performance variable of legislator d at time t. Each column presents the result of an OLS regression where the dependent variable is listed in the column. Column 1 is at the week level, column 2 at the year level and columns 3 and 4 at the quarter level. *Post* is a dummy indicating periods after the protests and *Protest Exposure* is an index reflecting the percentage of the legislator's electorate that lives in a municipality that had a demonstration: the higher the index, more exposure to the protests the legislator had. All regressions include time and legislator fixed-effects. Standard errors are clustered by legislator and displayed in brackets.

Once again, to test the significance of our protest variable on legislators' behavior, we plot in Figure 4.25 the marginal effects of our *Protest Exposure Index* for the pool of candidates running for reelection. For presence rate, we do not find significant coefficients. However, results for the share budget amendments show that, for low levels of noise, protests affect the pork barrel behavior of legislators. For the median legislator affected by protest (*Protest Exposure Index* = 0.451) who was running for reelection and who faced such low noise level (10th percentile), protests led to an increase of 4.01 pp on the share of budget amendments related to protests demands, which represents an increase of 22.5% relative to the pre-protest mean.

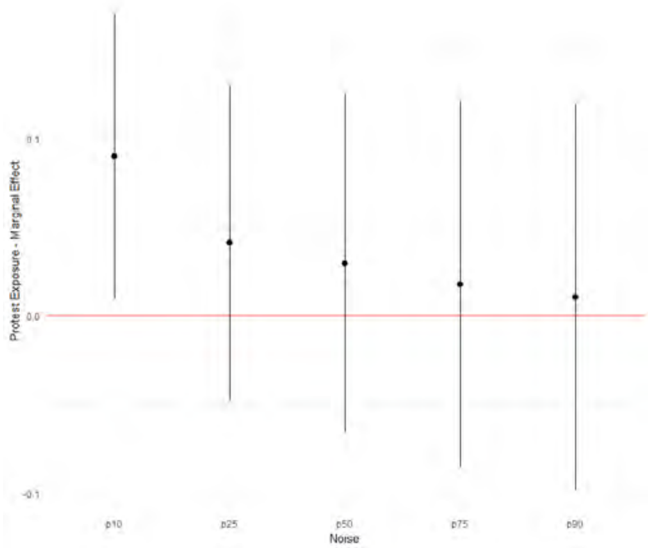


Figure 4.23: % budget amendments

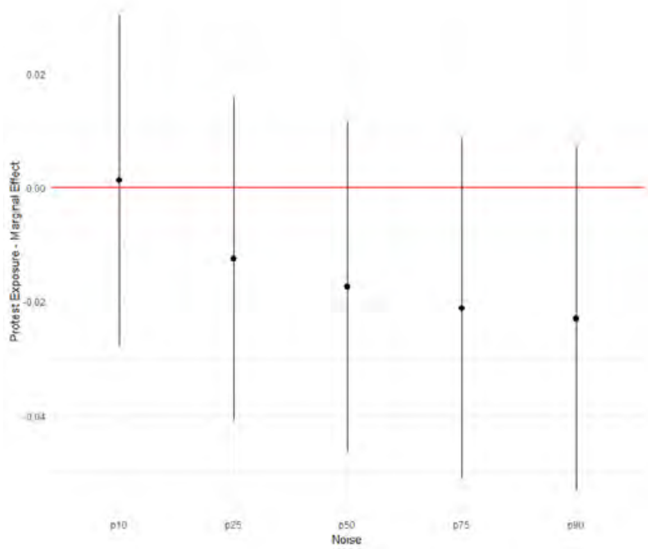


Figure 4.24: Presence rate

Figure 4.25: Reelection incentives: marginal effect of *Protest Exposure Index* for $Post = 1$ and different levels of *Noise Exposure Index* for legislators who run for reelection in 2014. CI at 95%.

This result is in line with our theoretical finding that protests may work as an accountability mechanism in the persuasion sense by impacting legislator´s choices, with higher noise leading to worst performance from legislators. Moreover, the rigidity of Brazil´s budget and the fact that the federal government has a lot of influence in most of the budget´s decision and execution still makes the pork barrel dimension would our preferred measure to explore legislator´s response to protests. Regarding the legislative duty, there is no significant effect of protest on bills that are related to protesters' demands. Elaborating more or less bills, in terms of number of bills, does not necessarily mean that protesters had their requests answered. Legislators may introduce legislation with no intention of ensuring that their bills are passed. Previous studies argue that Brazilian legislators submit bills, the Chamber registers them, and printed versions are sent to constituents as proof of legislative effort from the legislator (Novaes (1994)). However, the fact that legislators are not putting effort in proposing a bill even if it is just to show it at his bailiwick is an evidence that they do not use an easy margin to send positive signals when their electorate demonstrates.

With these results from legislators' behavior, where we find positive effects of protests only when reelection incentives exist and protesters demands are not noisy, in the next section we then analyze whether voters decided to punish legislators for their general lack of response in the 2014 elections.

4.6.2
Protests and Electoral Accountability

Considering rational voters, we expect them to condition their voting decision on incumbents' behavior. In this section we test whether legislators who responded more positively to protests were rewarded in the national elections following protests occurrence. To test the electoral accountability mechanism of protests, we analyze how each municipality that experienced a protest distributed its votes among incumbents who had a seat at the National Congress during June 2013. We constructed a balanced panel, presenting vote share in a 0-100 scale. Table 4.5 present the result of equation 4-10. Column (1) shows that, conditional on legislator-municipality fixed characteristics, incumbents were punished in municipalities with protests occurrence: on average, they lost 0.17 pp, which represents a decrease of 15.7% regarding the votes they received in the previous election.

Table 4.5: **Effect of legislators' behavior on electoral accountability**

Dep. Var.: vote share	(1)	(2)	(3)	(4)
Post	-0.174***	-0.273	-0.254***	-0.478***
	(0.0282)	(0.212)	(0.0357)	(0.119)
Post x % budg. amend. protest		0.131		
		(0.258)		
Post x Dummy bill rel. protest			0.181***	
			(0.0442)	
Post x Presence rate				0.369***
				(0.140)
Observations	26,344	25,960	26,344	26,344
Adjusted R-squared	0.870	0.869	0.870	0.870
Number of periods	2 elections	2 elections	2 elections	2 elections
Number of legislators	366	360	366	366
Mean Dep. Var. pre-protest	1.11	1.12	1.11	1.11
Legislator-municipality FE	Yes	Yes	Yes	Yes

Notes: This table reports the effects of the protests on legislators' performance. Observation unit is performance variable of legislator d at time t. Each column presents the result of an OLS regression where the dependent variable is listed in the column. Column 1 is at the week level, column 2 at the year level and columns 3 and 4 at the quarter level. *Post* is a dummy indicating periods after the protests and *Protest Exposure* is an index reflecting the percentage of the legislator's electorate that lives in a municipality that had a demonstration: the higher the index, more exposure to the protests the legislator had. All regressions include time and legislator fixed-effects. Standard errors are clustered by legislator and displayed in brackets.

As our main interest is on whether legislators' responses to protest correlate to voters' decision to punish or reward incumbents, columns (2) - (4) present the result of the interaction between legislators performance measured by the post-protest average on the outcomes previously evaluated. We find positive and significant effect of legislators' response in form of proposal of bills and presence in plenary. For legislators who proposed at lest 1 bill related to protest in the period after the protest, we see that voters still punish incumbents in the 2014 elections, but they punish less – the decrease of the votes from a municipality with protest is 0.07 pp, which represents a decrease of 6.6% relative to the 2010 election. Regarding presence in plenary, we see that the median legislator receives 0.16 pp less votes in , while legislator at the 90th percentile on the presence rate post-protest average distribution gets 0.12 pp.

To end up, we incorporate our measure of noise in each municipality to check how noisy demand might have positively allow voters to separate legislators with high performance after the protest vs. legislators with low performance. To do that, we split our municipalities sample into those ones that present high level of $Noise\ Index_m$ (above median) from municipalities with low $Noise\ Index_m$. Our theoretical model predicts that in municipalities where protesters messages were more noisy, voters would more easily distinguish between legislators that respond more positively to protests' demands. Thus, we expect municipalities above the median on the noise index to have bigger coefficients for the correlation of performance with vote share.

Table 4.6 presents the results, in where we only find significant coefficients for regression that refer to the legislative duty of legislators. Columns (3) and (4) show that legislators that presented at least one bill related to protest demand after June, were rewarded with 0.04 pp on the vote share, which represents an increase of 3.3% in the vote share from past elections. On the other hand, in the municipalities that presented less noisy demands, the increase is smaller, of 0.02 pp, representing an increase of 2.2% in the pre-protest vote share.

Table 4.6: **Noise and electoral accountability**

	High noise	Low noise	High noise	Low noise	High noise	Low noise
Dep. Var.: vote share	(1)	(2)	(3)	(4)	(5)	(6)
Post	0.0111	6.34e-05	-0.0801***	-0.136***	-0.206	-0.259*
	(0.0782)	(0.0879)	(0.0281)	(0.0341)	(0.130)	(0.151)
Post x % budg. amend. protest	-0.0598	-0.0918				
	(0.0987)	(0.107)				
Post x Dummy bill rel. protest			0.117***	0.161***		
			(0.0354)	(0.0442)		
Post x Presence rate					0.216	0.237
					(0.158)	(0.182)
Observations	14,826	11,134	15,050	11,294	15,050	11,294
Adjusted R-squared	0.885	0.892	0.884	0.894	0.884	0.893
Number of periods	2 elections	2 elections	2 elections	2 elections	2 elections	2 elections
Number of legislators	326	353	332	359	332	359
Number of municipalities	241	192	241	192	241	192
Mean Dep. Var. pre-protest	1.12	1.13	1.11	1.13	1.11	1.13
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Legislator-municipality FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the effects of the protests on legislators' performance. Observation unit is performance variable of legislator d at time t. Each column presents the result of an OLS regression where the dependent variable is listed in the column. Column 1 is at the week level, column 2 at the year level and columns 3 and 4 at the quarter level. *Post* is a dummy indicating periods after the protests and *Protest Exposure* is an index reflecting the percentage of the legislator's electorate that lives in a municipality that had a demonstration: the higher the index, more exposure to the protests the legislator had. All regressions include time and legislator fixed-effects. Standard errors are clustered by legislator and displayed in brackets.

4.7 Conclusion

Although the political economy literature has extensive work on elections as an accountability mechanism, less is known about other social accountability mechanisms, such as protests. In particular, to the best of our knowledge, no work has analyzed the effect of the quality of the information delivered by protesters on accountability.

Theoretically, our modelling strategy was to model protests a noisy Bayesian persuasion mechanism. We show that while protests can be successful as an accountability mechanism from a persuasion perspective – protests can induce government´s to behave as voters want. However, the noisier the protest message, the less successful protest would be. In fact, they can ex-ante unsuccessful if the level of noise is ”too high”. We then followed with how noise impacts electoral accountability. Interestingly, noisier protests can help protesters to separate high from low quality politicians – and so, improve electoral accountability, conditionally on the policy action delivered by politicians after the protest. The intuition from the result is the following. Noisier protests are harder to read from the perspective of the politicians. Therefore, if the voters observed the politician has delivered their preferred action, they attach higher probability that this is a high quality politician.

We then followed to estimate the effect of Brazil mass street protests on both legislators and voters behavior. We have found empirical evidence that the quality of information provided in protests matter for accountability, in particular to accountability as persuasion – voters getting what they want from the government. In fact, we find positive significant effects from protests only for low levels of noise and when reelection incentives are at stake: "sharper" protests mean higher pork barrel spending by legislators that were exposed in their congressional basis protests. This evidence goes in line with recent research that show that street movements with clear goals, such environmental concerns, can lead to long-term effects on citizens’ beliefs and behavior (Hungerman and Moorthy (2022)).

We see our findings as important for understanding the effects of social accountability mechanisms, such as mass street protests, on political accountability. In particular, it is important to disentangle the intensity of protests from the how clarity of the message that is delivered by them to politicians. If citizens go out to protest, some level of coordination seems required so that protests can be a success persuasion mechanism.

4.8 Appendix

4.8.1 Figures

..

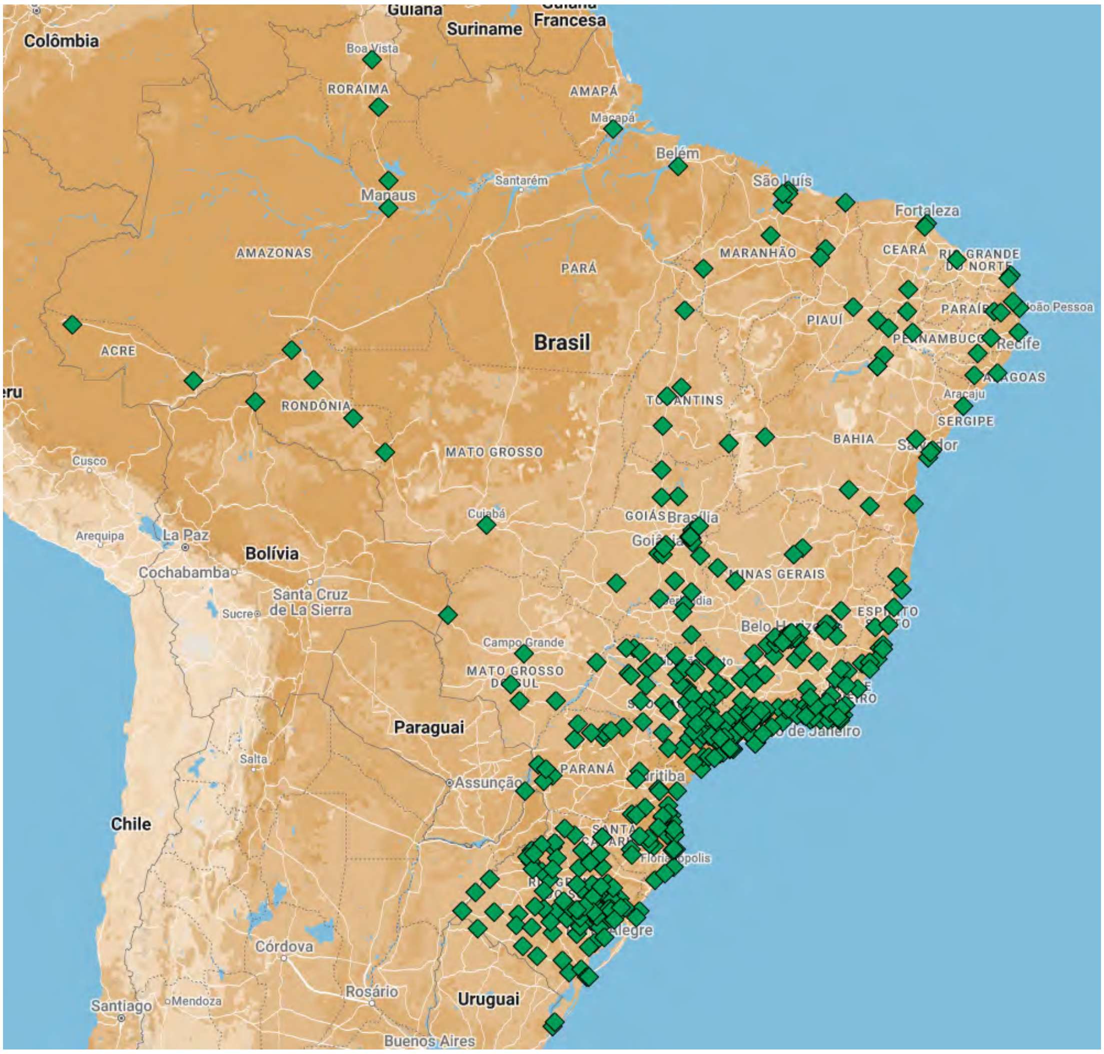


Figure 4.26: **Municipalities that experienced at least one protest in 2013.**

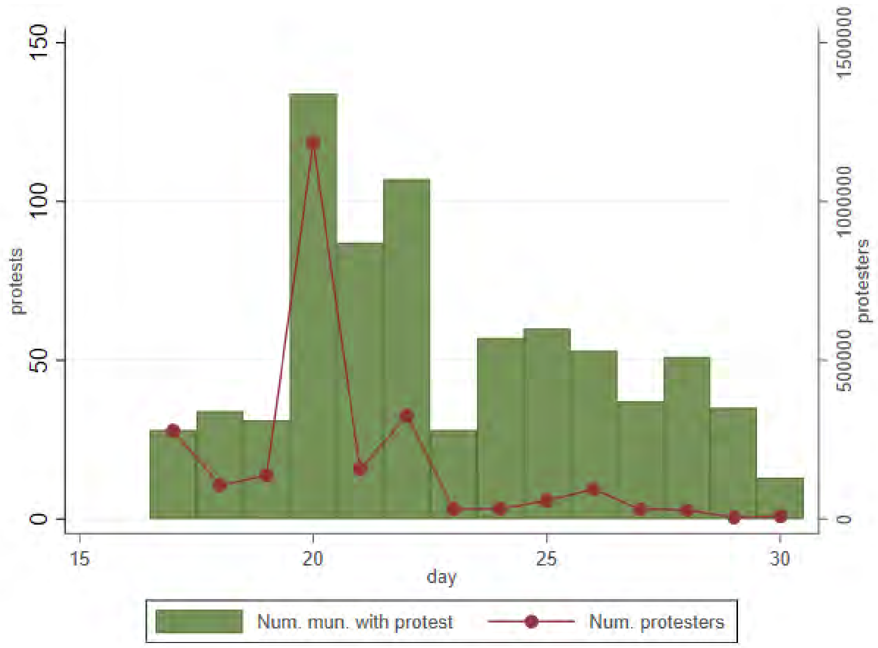


Figure 4.27: **Number of protesters and municipalities that had a protests from June 17th till June 30th.**

Note: Data from G1.

4.8.2 Tables

Table 4.7: **Protest occurrence by state**

State	% municipalities that had a protest	% population that lives in a municipality that had a protest
DF	100,0%	100,0%
RJ	41,3%	84,4%
RS	19,8%	70,7%
SP	16,3%	69,5%
RR	13,3%	68,5%
AP	6,3%	59,5%
SC	10,9%	52,6%
AM	3,2%	52,5%
MS	7,7%	51,9%
ES	12,8%	50,9%
AC	9,1%	47,8%
GO	6,9%	47,7%
RO	9,6%	45,8%
MG	5,5%	44,4%
PR	4,3%	43,5%
RN	1,8%	40,0%
AL	2,0%	36,7%
CE	2,2%	35,6%
PI	1,8%	34,3%
TO	3,6%	34,3%
BA	2,6%	33,2%
PB	1,8%	31,0%
PE	4,3%	28,4%
SE	1,3%	27,6%
MA	2,8%	23,8%
PA	0,7%	18,4%
MT	0,7%	18,2%

Notes: Data from protests collected from G1, a news website. Population data extracted from 2010 census.

Table 4.8: **List of words used for Twitter query**

Protest tweets	**Demands**
(1)	(2)
protest	educacao
manifest	saude
movimento passe livre	hospitais
democracia	hospital
nao e so por 20 centavos	medico
nao e por 20 centavos	corrupcao
naoesopor20centavos	copa
naoepor20centavos	estadio
ogiganteacordou	roub
o gigante acordou	pec37
vemprarua	transporte
vem pra rua	passagem de onibus
govern	passagem do onibus
prefeit	preco do onibus
deputad	seguranca
vereador	
congresso nacional	
senado	
politico	
presidente	
eleicao	

Notes: Twitter API uses a "fuzzy matching" technique for it queries, which allow us to find tweets using only the root of the words.

Table 4.9: **Effect of protests on legislators' behavior - reelection incentives**

	% budgt. amend.		Dummy bill rel. prot.		Presence rate	
	reelection=1	reelection=0	reelection=1	reelection=0	reelection=1	reelection=0
	(1)	(2)	(3)	(4)	(5)	(6)
Post x Protest Exposure	0.0188	-0.0800	0.00463	0.0734	-0.00874	-0.0343
	(0.0497)	(0.0776)	(0.0349)	(0.0543)	(0.0160)	(0.0314)
Constant	0.175***	0.184***	0.109***	0.0824***	0.840***	0.797***
	(0.00858)	(0.0121)	(0.00618)	(0.00856)	(0.00430)	(0.00751)
Observations	658	243	4,879	1,819	15,635	6,132
Adjusted R-squared	0.575	0.485	0.117	0.112	0.218	0.229
Mean Dep. Var. pre-protest	0.18	0.18	0.18	0.18	0.18	0.18
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Legislator FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports the effects of the protests on legislators' performance. Observation unit is performance variable of legislator d at time t. Each column presents the result of an OLS regression where the dependent variable is listed in the column. Column 1 is at the week level, column 2 at the year level and columns 3 and 4 at the quarter level. *Post* is a dummy indicating periods after the protests and $Protest\ Exposure$ is an index reflecting the percentage of the legislator's electorate that lives in a municipality that had a demonstration: the higher the index, more exposure to the protests the legislator had. All regressions include time and legislator fixed-effects. Standard errors are clustered by legislator and displayed in brackets.

C
Proofs

C.0
Proof of Proposition 4.1

Prova. Fix $\mu = \Pr(\omega = 1) \in (0, 0.5)$ and $a = 1$ the action protesters would prefer the government to choose. The protesters will choose the fourthuple $(q_0^L, q_1^L, q_0^H, q_1^H)$ of probabilities:

	$\pi(s = 0\|\omega, L)$	$\pi(s = 1\|\omega, L)$
$\omega = 0$	$1 - q_0^L$	q_0^L
$\omega = 1$	$1 - q_1^L$	q_1^L

	$\pi(s = 0\|\omega, H)$	$\pi(s = 1\|\omega, H)$
$\omega = 0$	$1 - q_0^H$	q_0^H
$\omega = 1$	$1 - q_1^H$	q_1^H

Table 4.10: Signal structure for low and high types of government.

The choice of the fourthuple $(q_0^L, q_1^L, q_0^H, q_1^H)$ is such that the expected payoff of protesters is maximized. Recall that the protesters only receive payoff of 1 when $a = 1$ and the government delivers $a = 1$ whenever $\Pr(\omega = 1|s') > 0.5$. Therefore, the protesters will solve this system of four inequalities $\Pr(\omega = 1|s' = 0, \tau = H) \geq \frac{1}{2}, \Pr(\omega = 1|s' = 1, \tau = H) \geq \frac{1}{2}, \Pr(\omega = 1|s' = 0, \tau = L) \geq \frac{1}{2}, \Pr(\omega = 1|s' = 1, \tau = L) \geq \frac{1}{2}$. We will use Baye's rule for the updates. Let's start with the high type of government, recalling that the type of government and the true state of the world are independent. Let's start with $s' = 1$ recalling that for the high type of government, $s' = 1$ can only happen when $s = 0$, since there is no noise in the communication channel:

$$\begin{aligned}
\Pr(\omega = 1|s' = 1, \tau = H) &= \frac{\Pr(s' = 1|\omega = 1, \tau = H)\Pr(\omega = 1)}{\Pr(s' = 1)} \geq \frac{1}{2} \\
&= \frac{q_1^H \mu_0}{q_1^H \mu_0 + q_0^H (1 - \mu_0)} \geq \frac{1}{2} \\
\frac{\mu_0}{1 - \mu_0} &\geq \frac{q_0^H}{q_1^H}
\end{aligned} \tag{4-15}$$

Now let's assume $s' = 0$:

$$\Pr(\omega = 1|s' = 0, \tau = H) = \frac{\Pr(s' = 0|\omega = 1, \tau = H)\Pr(\omega = 1)}{\Pr(s' = 0)} \geq \frac{1}{2}$$

$$= \frac{(1 - q_1^H)\mu_0}{(1 - q_1^H)\mu_0 + (1 - q_0^H)(1 - \mu_0)} \geq \frac{1}{2}$$

$$\frac{\mu_0}{1 - \mu_0} \geq \frac{1 - q_0^H}{1 - q_1^H} \quad (4\text{-}16)$$

First, note that the likelihood ratio delivered by the inequality 4-15 is inconsistent with the inequality delivered by 4-16. However, since the payoff of the protesters is increasing in q_0^H and q_1^H, we find that the solution of this problem is given by $q_1^H = 1$ and with 4-15 holding with equality, which delivers $q_0^H = \frac{\mu_0}{1-\mu_0}$.

Now we have to find the optimal solutions for the case in which the government is low type. We start with $s' = 1$. Now, since $\tau = L$, $s' = 1$ because there was no noise and so $s = 1$ or because there was noise and $s = 0$. Recall that the noise process is independent of the type of the government and of the state of the world and note that and $\Pr(s' = 1|\omega = 1, \tau = L)\Pr(\omega = 1) = (\Pr(s' = 1|\omega = 1, \tau = L, s = 1) + \Pr(s' = 1|\omega = 1, \tau = L, s = 0))\Pr(\omega = 1)$ $\Pr(s' = 1) = (\Pr(s' = 1|\omega = 1, \tau = L, s = 1) + \Pr(s' = 1|\omega = 1, \tau = L, s = 0))\Pr(\omega = 1) + (\Pr(s' = 1|\omega = 0, \tau = L, s = 1) + \Pr(s' = 1|\omega = 0, \tau = L, s = 0))\Pr(\omega = 0)$.

$$\Pr(\omega = 1|s' = 1, \tau = L) = \frac{\Pr(s' = 1|\omega = 1, \tau = L)\Pr(\omega = 1)}{\Pr(s' = 1)} \geq \frac{1}{2}$$

Using the definitions for $\Pr(s' = 1|\omega = 1, \tau = L)$ and for $\Pr(s' = 1)$ from above and the fact that the payoff of the protesters is increasing in q_0^L and q_1^L, with simple algebra we find that the optimal probabilities are $q_1^L = 1$ and $q_0^L = \frac{\mu_0 - \epsilon}{(1-\mu_0)(1-2\epsilon)}$. For q_0^L to be a probability we require that (i) $\mu_0 > \epsilon$ and $\epsilon < 0.5$ or (ii) $\mu_0 < \epsilon$ and $\epsilon > 0.5$. Since $\epsilon < 0.5$ is not only the most intuitive assumption – a small error – but also the only one that matches the equilibrium we are describing here, we follow with (i).

Since we have the fourthuple $(q_0^L, q_1^L, q_0^H, q_1^H)$, we can go back and compute the posteriors for all types of government. With simple algebra we find the posteriors mentioned in Proposition 4.1. ■

5 Bibliography

Alencar, Ane A., Paulo M. Brando, Gregory P. Asner, and Francis E. Putz, "Landscape fragmentation, severe drought, and the new Amazon forest fire regime," *Ecological Applications*, 9 2015, *25*, 1493–1505. Cited in page 29.

Araujo, Rafael, "Mapping the Effect of Deforestation on Rainfall: A Case Study from the State of Mato Grosso.," 2021. Cited in page 22.

Ashraf, Nava, Oriana Bandiera, and B. Kelsey Jack, "No margin, no mission? A field experiment on incentives for public service delivery," *Journal of Public Economics*, 12 2014, *120*, 1–17. Cited in page 52.

—, —, Edward Davenport, and Scott S. Lee, "Losing Prosociality in the Quest for Talent? Sorting, Selection, and Productivity in the Delivery of Public Services," *American Economic Review*, 5 2020, *110*, 1355–1394. Cited 2 times in pages 52 and 76.

Assunção, Juliano and Flávia Chein, "Climate change and agricultural productivity in Brazil: future perspectives," *Environment and Development Economics*, 10 2016, *21*, 581–602. Cited in page 22.

Atkin, David, Azam Chaudhry, Shamyla Chaudry, Amit K. Khandelwal, and Eric Verhoogen, "Organizational Barriers to Technology Adoption: Evidence from Soccer-Ball Producers in Pakistan*," *The Quarterly Journal of Economics*, 8 2017, *132*, 1101–1164. Cited in page 47.

Atnafu, Asmamaw, Damen Haile Mariam, Rex Wong, Taddese Awoke, and Yitayih Wondimeneh, "Improving Adult ART Clinic Patient Waiting Time by Implementing an Appointment System at Gondar University Teaching Hospital, Northwest Ethiopia," *Advances in Public Health*, 2015, *2015*, 1–5. Cited 2 times in pages 50 and 53.

Auffhammer, Maximilian and Wolfram Schlenker, "Empirical studies on agricultural impacts and adaptation," *Energy Economics*, 11 2014, *46*, 555–561. Cited in page 22.

—, Solomon M. Hsiang, Wolfram Schlenker, and Adam Sobel, "Using Weather Data and Climate Model Output in Economic Analyses of Climate Change," *Review of Environmental Economics and Policy*, 7 2013, *7*, 181–198. Cited in page 32.

—, V. Ramanathan, and Jeffrey R. Vincent, "Integrated model shows that atmospheric brown clouds and greenhouse gases have reduced rice harvests in India," *Proceedings of the National Academy of Sciences*, 12 2006, *103*, 19668–19672. Cited in page 22.

Austin, Emily E., Kyle Wickings, Marshall D. McDaniel, G. Philip Robertson, and A. Stuart Grandy, "Cover crop root contributions to soil carbon in a no-till corn bioenergy cropping system," *GCB Bioenergy*, 7 2017, *9*, 1252–1263. Cited in page 27.

Baldocchi, Dennis, "Managing land and climate," *Nature Climate Change*, 5 2014, *4*, 330–331. Cited in page 29.

Bangsberg, David R, Edwin D Charlebois, Robert M Grant, Mark Holodniy, Steven G Deeks, Sharon Perry, Kathleen Nugent Conroy, Richard Clark, David Guzman, Andrew Zolopa, and Andrew Moss, "High levels of adherence do not prevent accumulation of HIV drug resistance mutations," *AIDS*, 9 2003, *17*, 1925–1932. Cited in page 54.

Bank, World, "Carbon sequestration in agricultural soils," *World Bank Group*, 2012. Cited 2 times in pages 24 and 27.

Barbera, Salvador and Matthew O Jackson, "A Model of Protests, Revolution, and Information," Technical Report 2016. Cited in page 89.

Basinga, Paulin, Paul J Gertler, Agnes Binagwaho, Agnes LB Soucat, Jennifer Sturdy, and Christel MJ Vermeersch, "Effect on maternal and child health services in Rwanda of payment to primary health-care providers for performance: an impact evaluation," *The Lancet*, 4 2011, *377*, 1421–1428. Cited in page 52.

Battaglini, Marco, "Public Protests and Policy Making," Technical Report 2016. Cited in page 89.

Bavinton, Benjamin R. and Alison J. Rodger, "Undetectable viral load and HIV transmission dynamics on an individual and population level," *Current Opinion in Infectious Diseases*, 2 2020, *33*, 20–27. Cited in page 54.

Beaman, Lori, Ariel BenYishay, Jeremy Magruder, and Ahmed Mushfiq Mobarak, "Can Network Theory-Based Targeting Increase Technology Adoption?," *American Economic Review*, 6 2021, *111*, 1918–1943. Cited in page 47.

—, Dean Karlan, Bram Thuysbaert, and Christopher Udry, "Profitability of Fertilizer: Experimental Evidence from Female Rice Farmers in Mali," *American Economic Review*, 5 2013, *103*, 381–386. Cited in page 23.

Behrer, A, "Earth, Wind and Fire: The impact of anti-poverty efforts on India agriculture and air pollution," 2019. Cited in page 29.

Bertholini, Frederico, Bernardo Guelber Fajardo, Diego de Faveri, and Carlos Pereira, "Does Legislative Work Help Reelection? Ambition, Reelection and Legislative Performance at the Subnational Level in Brazil.," *SSRN Electronic Journal*, 2013. Cited in page 89.

Bertrand, Marianne, Robin Burgess, Arunish Chawla, and Guo Xu, "The Glittering Prizes: Career Incentives and Bureaucrat Performance," *The Review of Economic Studies*, 5 2019. Cited in page 52.

Bianchi, F.J.J.A, C.J.H Booij, and T Tscharntke, "Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control," *Proceedings of the Royal Society B: Biological Sciences*, 7 2006, *273*, 1715–1727. Cited in page 20.

Bidner, Chris and Patrick Francois, "The emergence of political accountability," *Quarterly Journal of Economics*, 2013, *128* (3), 1397–1448. Cited in page 116.

Bisson, Gregory P, Robert Gross, Scarlett Bellamy, Jesse Chittams, Michael Hislop, Leon Regensberg, Ian Frank, Gary Maartens, and Jean B Nachega, "Pharmacy Refill Adherence Compared with CD4 Count Changes for Monitoring HIV-Infected Adults on Antiretroviral Therapy," *PLoS Medicine*, 5 2008, *5*, e109. Cited in page 54.

Björkman, Martina and Jakob Svensson, "WHEN IS COMMUNITY-BASED MONITORING EFFECTIVE? EVIDENCE FROM A RANDOMIZED EXPERIMENT IN PRIMARY HEALTH IN UGANDA," *Journal of the European Economic Association*, 4 2010, *8*, 571–581. Cited in page 76.

Blanco-Canqui, Humberto, Tim M. Shaver, John L. Lindquist, Charles A. Shapiro, Roger W. Elmore, Charles A. Francis, and Gary W. Hergert, "Cover Crops and Ecosystem Services: Insights from Studies in Temperate Soils," *Agronomy Journal*, 11 2015, *107*, 2449–2474. Cited in page 21.

Bloom, N., R. Sadun, and J. Van Reenen, "Does Management Matter in Healthcare?," 2014. Cited in page 53.

Boone, Claire E, Pablo Celhay, Paul Gertler, Tadeja Gracner, and Josefina Rodriguez, "How scheduling systems with automated appointment reminders improve health clinic efficiency," *Journal of Health Economics*, 3 2022, *82*, 102598. Cited in page 53.

Bragança, Arthur, Peter Newton, Avery Cohn, Juliano Assunção, Cristiane Camboim, Diego de Faveri, Barbara Farinelli, Viviana ME Perego, Mateus Tavares, Janei Resende et al., "Extension services can promote pasture restoration: Evidence from Brazil's low carbon agriculture plan," *Proceedings of the National Academy of Sciences*, 2022, *119* (12), e2114913119. Cited in page 47.

Brando, P. M., B. Soares-Filho, L. Rodrigues, A. Assunção, D. Morton, D. Tuchschneider, E. C. M. Fernandes, M. N. Macedo, U. Oliveira, and M. T. Coe, "The gathering firestorm in southern Amazonia," *Science Advances*, 1 2020, *6*. Cited in page 29.

Brando, Paulo Monteiro, Jennifer K. Balch, Daniel C. Nepstad, Douglas C. Morton, Francis E. Putz, Michael T. Coe, Divino Silvério, Marcia N. Macedo, Eric A. Davidson, Caroline C. Nóbrega, Ane Alencar, and Britaldo S. Soares-Filho, "Abrupt increases in Amazonian tree mortality due to drought–fire interactions," *Proceedings of the National Academy of Sciences*, 4 2014, *111*, 6347–6352. Cited in page 29.

Burke, Marshall and David B. Lobell, "Satellite-based assessment of yield variation and its determinants in smallholder African systems," *Proceedings of the National Academy of Sciences*, 2 2017, *114*, 2189–2194. Cited in page 21.

__, Anne Driscoll, David B. Lobell, and Stefano Ermon, "Using satellite imagery to understand and promote sustainable development," *Science*, 3 2021, *371*. Cited in page 26.

__, Solomon M. Hsiang, and Edward Miguel, "Climate and Conflict," *Annual Review of Economics*, 8 2015, *7*, 577–617. Cited in page 47.

Bustos, Paula, Bruno Caprettini, and Jacopo Ponticelli, "Agricultural Productivity and Structural Transformation: Evidence from Brazil," *American Economic Review*, 6 2016, *106*, 1320–1365. Cited in page 20.

Caballero, Cassia Brocca, Anderson Ruhoff, and Trent Biggs, "Land use and land cover changes and their impacts on surface-atmosphere interactions in Brazil: A systematic review," *Science of The Total Environment*, 2 2022, *808*, 152134. Cited in page 28.

Callen, Michael, Saad Gulzar, Ali Hasanain, Muhammad Yasir Khan, and Arman Rezaee, "Data and policy decisions: Experimental evidence from Pakistan," *Journal of Development Economics*, 9 2020, *146*, 102523. Cited in page 52.

Campante, Filipe R and Davin Chor, "Schooling, political participation, and the economy," *Review of Economics and Statistics*, 2012, *94* (4), 841–859. Cited in page 89.

Cantoni, Davide, David Y. Yang, Noam Yuchtman, and Y. Jane Zhang, "Protests as strategic games: Experimental evidence from Hong Kong's antiauthoritarian movement," *Quarterly Journal of Economics*, 2019, *134* (2), 1021–1077. Cited in page 93.

Carleton, Tamma A. and Solomon M. Hsiang, "Social and economic impacts of climate," *Science*, 9 2016, *353*. Cited in page 22.

Chen, Yanan, Hongfan Gu, Munan Wang, Qing Gu, Zhi Ding, Mingguo Ma, Rongyuan Liu, and Shuguang Tang, "Contrasting Performance of the Remotely-Derived GPP Products over Different Climate Zones across China," *Remote Sensing*, 8 2019, *11*, 1855. Cited in page 27.

Chesney, Margaret A., "Factors Affecting Adherence to Antiretroviral Therapy," *Clinical Infectious Diseases*, 6 2000, *30*, S171–S176. Cited in page 55.

Chivasa, Walter, Onisimo Mutanga, and Chandrashekhar Biradar, "Application of remote sensing in estimating maize grain yield in heterogeneous African agricultural landscapes: a review," *International Journal of Remote Sensing*, 12 2017, *38*, 6816–6845. Cited in page 26.

Cohen, Myron S., Ying Q. Chen, Marybeth McCauley, Theresa Gamble, Mina C. Hosseinipour, Nagalingeswaran Kumarasamy, James G. Hakim, Johnstone Kumwenda, Beatriz Grinsztejn, Jose H.S. Pilotto, Sheela V. Godbole, Sanjay Mehendale, Suwat Chariyalertsak, Breno R. Santos, Kenneth H. Mayer, Irving F. Hoffman, Susan H. Eshleman, Estelle Piwowar-Manning, Lei Wang, Joseph Makhema, Lisa A. Mills, Guy de Bruyn, Ian Sanne, Joseph Eron, Joel Gallant, Diane Havlir, Susan Swindells, Heather Ribaudo, Vanessa Elharrar, David Burns, Taha E. Taha, Karin Nielsen-Saines, David Celentano, Max Essex, and Thomas R. Fleming, "Prevention of HIV-1 Infection with Early Antiretroviral Therapy," *New England Journal of Medicine*, 8 2011, *365*, 493–505. Cited in page 54.

Cohn, Avery S., Leah K. VanWey, Stephanie A. Spera, and John F. Mustard, "Cropping frequency and area response to climate variability can exceed yield response," *Nature Climate Change*, 6 2016, *6*, 601–604. Cited in page 22.

Contreras-Loya, David, Paul Gertler, and Ada Kwan, "Managerial Practices and Altruism in Health Care Delivery," *Working paper*, 2021. Cited 3 times in pages 50, 53, and 76.

Correa, Sofia, "Persistent Protests," Technical Report 2020. Cited in page 89.

Costa, Marcos H., Silvia N. M. Yanagi, Paulo J. O. P. Souza, Aristides Ribeiro, and Edson J. P. Rocha, "Climate change in Amazonia caused by soybean cropland expansion, as compared to caused by pastureland expansion," *Geophysical Research Letters*, 4 2007, *34*, L07706. Cited in page 28.

Costa, Marcos Heil and Gabrielle Ferreira Pires, "Effects of Amazon and Central Brazil deforestation scenarios on the duration of the dry season in the arc of deforestation," *International Journal of Climatology*, 11 2010, *30*, 1970–1979. Cited 2 times in pages 28 and 41.

Câmara, Gilberto, Michelle Picoli, Adeline Maciel, Rolf Simoes, Lorena Santos, Pedro R Andrade, Karine Ferreira, Rodrigo Begotti, Ieda Sanches, Alexandre X Y Carvalho, Alexandre Coutinho, Julio Esquerdo, Joao Antunes, and Damien Arvor, "Land cover change maps for Mato Grosso State in Brazil: 2001-2017 (version 3)," 2019. Cited in page 25.

da Silva, Paulo Claudeir Gomes, Carlos Sérgio Tiritan, Fábio Rafael Echer, Carlos Felipe dos Santos Cordeiro, Melina Daniel Rebonatti, and Carlos Henrique dos Santos, "No-tillage and crop rotation increase crop yields and nitrogen stocks in sandy soils under agroclimatic risk," *Field Crops Research*, 11 2020, *258*, 107947. Cited in page 21.

Dal-Bó, Ernesto, Frederico Finan, and Martín A. Rossi, "Strengthening State Capabilities: The Role of Financial Incentives in the Call to Public Service*," *The Quarterly Journal of Economics*, 8 2013, *128*, 1169–1218. Cited in page 52.

—, Nicholas Y. Li, and Laura Schechter, "Information Technology and Government Decentralization: Experimental Evidence From Paraguay," *Econometrica*, 2021, *89*, 677–701. Cited in page 52.

Dalhaus, Tobias, Wolfram Schlenker, Michael M. Blanke, Esther Bravin, and Robert Finger, "The Effects of Extreme Weather on Apple Quality," *Scientific Reports*, 12 2020, *10*, 7919. Cited in page 2.

Dabis, Halima, Lynne M. Mofenson, Rene Ekpini, Charles F. Gilks, Matthew Barnhart, Omotayo Bolu, and Nathan Shaffer, "International recommendations on antiretroviral drugs for treatment of HIV-infected women and prevention of mother-to-child HIV transmission in resource-limited settings: 2006 update," *American Journal of Obstetrics and Gynecology*, 9 2007, *197*, S42–S55. Cited in page 54.

de Sá, Saraly Andrade, Charles Palmer, and Salvatore di Falco, "Dynamics of indirect land-use change: Empirical evidence from Brazil," *Journal of Environmental Economics and Management*, 5 2013, *65*, 377–393. Cited in page 22.

de Walque, Damien, Paul J. Gertler, Sergio Bautista-Arredondo, Ada Kwan, Christel Vermeersch, Jean de Dieu Bizimana, Agnès Binagwaho, and Jeanine Condo, "Using provider performance incentives to increase HIV testing and counseling services in Rwanda," *Journal of Health Economics*, 3 2015, *40*, 1–9. Cited in page 52.

Dean, Jill E. and Ray R. Weil, "Brassica Cover Crops for Nitrogen Retention in the Mid-Atlantic Coastal Plain," *Journal of Environmental Quality*, 3 2009, *38*, 520–528. Cited in page 21.

Deserranno, Erika, "Financial Incentives as Signals: Experimental Evidence from the Recruitment of Village Promoters in Uganda," *American Economic Journal: Applied Economics*, 1 2019, *11*, 277–317. Cited in page 52.

Dhaliwal, Iqbal and Rema Hanna, "The devil is in the details: The successes and limitations of bureaucratic reform in India," *Journal of Development Economics*, 1 2017, *124*, 1–21. Cited in page 52.

Dias, Lívia Cristina Pinto, Márcia N. Macedo, Marcos Heil Costa, Michael T. Coe, and Christopher Neill, "Effects of land cover change on evapotranspiration and streamflow of small catchments in the Upper Xingu River Basin, Central Brazil," *Journal of Hydrology: Regional Studies*, 9 2015, *4*, 108–122. Cited in page 28.

Dias, Mateus, Rocha Rudi, and Rodrigo Soares, "Glyphosate Use in Agriculture and Birth Outcomes of Surrounding Populations," 2019. Cited 2 times in pages 19 and 22.

Doerr, Stefan H. and Cristina Santín, "Global trends in wildfire and its impacts: perceptions versus realities in a changing world," *Philosophical Transactions of the Royal Society B: Biological Sciences*, 6 2016, *371*, 20150345. Cited in page 29.

Donaldson, Dave and Adam Storeygard, "The View from Above: Applications of Satellite Data in Economics," *Journal of Economic Perspectives*, 11 2016, *30*, 171–198. Cited in page 21.

Donato, Katherine, Grant Miller, Manoj Mohanan, Yulya Truskinovsky, and Marcos Vera-Hernández, "Personality Traits and Performance Contracts: Evidence from a Field Experiment among Maternity Care Providers in India," *American Economic Review*, 5 2017, *107*, 506–510. Cited in page 52.

do S. Cordeiro, Carlos F., Guilherme D. Batista, Bruno P. Lopes, and Fábio R. Echer, "Cover crop increases soybean yield cropped after degraded pasture in sandy soil," *Revista Brasileira de Engenharia Agrícola e Ambiental*, 8 2021, *25*, 514–521. Cited in page 21.

Duflo, Esther, Michael Kremer, and Jonathan Robinson, "How High Are Rates of Return to Fertilizer? Evidence from Field Experiments in Kenya," *American Economic Review*, 4 2008, *98*, 482–488. Cited in page 36.

_, _, and _ , "Nudging Farmers to Use Fertilizer: Theory and Experimental Evidence from Kenya," *American Economic Review*, 10 2011, *101*, 2350–2390. Cited 2 times in pages 23 and 47.

_, Rema Hanna, and Stephen P Ryan, "Incentives Work: Getting Teachers to Come to School," *American Economic Review*, 6 2012, *102*, 1241–1278. Cited in page 52.

Dunsch, Felipe, David Evans, Ezinne Eze-Ajoku, and Mario Macis, "Management, Supervision, and Health Care: A Field Experiment," *NBER Working paper*, 2021. Cited 3 times in pages 50, 53, and 76.

Elbakidze, Levan, Yuele Xu, Philip Gassman, Jeffrey Arnold, and Haw Yen, "Climate Change and Downstream Water Quality in Agricultural Production: The Case of Nutrient Runoff to the Gulf of Mexico," 2022. Cited in page 22.

Emerick, Kyle, Alain de Janvry, Elisabeth Sadoulet, and Manzoor H. Dar, "Technological Innovations, Downside Risk, and the Modernization of Agriculture," *American Economic Review*, 6 2016, *106*, 1537–1561. Cited in page 23.

et al. Watson, Robert, "Land Use, Land-Use Change, and Forestry.," 2000. Cited in page 27.

FAO, "Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56," 1998. Cited 2 times in pages 23 and 28.

__ , *Recarbonizing global soils – A technical manual of recommended management practices*, FAO, 9 2021. Cited 2 times in pages 24 and 42.

Ferraz, Claudio and Frederico Finan, "Exposing corrupt politicians: the effects of Brazil's publicly released audits on electoral outcomes," *The Quarterly journal of economics*, 2008, *123* (2), 703–745. Cited in page 87.

Firpo, Sergio, Vladimir Ponczek, and Viviane Sanfelice, "The relationship between federal budget amendments and local electoral power," *Journal of Development Economics*, 2015, *116*, 186–198. Cited in page 112.

F Matthew P. and Sydney Rosen, "Retention of Adult Patients on Antiretroviral Therapy in Low- and liddle-Income Countries," *JAIDS Journal of Acquired Immune Deficiency Syndromes*, 5 2015, *69*, 98–108. ited in page 51.

F raldenhoven, Simon, Christian Hansen, and Jesse M. Shapiro, "Pre-Event Trends in the Panel Event-udy Design," *American Economic Review*, 9 2019, *109*, 3307–3338. Cited in page 43.

F wara, T, K Mueller, and C Schwarz, "The Effect of Social Media on Elections: Evidence from the nited States," *Working paper*, 2022. Cited in page 113.

G liarducci, Stefano, Tommaso Nannicini, and Paolo Naticchioni, "Electoral Rules and Politicians' ehavior: A Micro Test," *American Economic Journal: Economic Policy*, 8 2011, *3*, 144–174. Cited 2 times in pages 90 and 113.

Garcia-Montiel, Diana C., Michael T. Coe, Meyr P. Cruz, Joice N. Ferreira, Euzebio M. da Silva, and Eric A. Davidson, "Estimating Seasonal Changes in Volumetric Soil Water Content at Landscape Scales in a Savanna Ecosystem Using Two-Dimensional Resistivity Profiling," *Earth Interactions*, 3 2008, *12*, 1–25. Cited in page 41.

Gaudin, Amélie C. M., Tor N. Tolhurst, Alan P. Ker, Ken Janovicek, Cristina Tortora, Ralph C. Martin, and William Deen, "Increasing Crop Diversity Mitigates Weather Variations and Improves Yield Stability," *PLOS ONE*, 2 2015, *10*, e0113261. Cited in page 21.

Giuntella, Osea, Catia Nicodemo, and Carlos Vargas-Silva, "The effects of immigration on NHS waiting times," *Journal of Health Economics*, 3 2018, *58*, 123–143. Cited in page 75.

Glewwe, Paul, Nauman Ilias, and Michael Kremer, "Teacher Incentives," *American Economic Journal: Applied Economics*, 7 2010, *2*, 205–227. Cited in page 52.

Gong, Estelle, Janeth Dula, Carla Alberto, Amanda de Albuquerque, Maria Steenland, Quinhas Fernandes, Rosa Marlene Cuco, Sandra Sequeira, Sérgio Chicumbe, Eduardo Samo Gudo, and Margaret McConnell, "Client experiences with antenatal care waiting times in southern Mozambique," *BMC Health Services Research*, 12 2019, *19*, 538. Cited 2 times in pages 56 and 57.

Gough, Christopher, "Terrestrial Primary Production: Fuel for Life," *Nature Education Knowledge*, 2011. Cited in page 39.

Govindasamy, Darshini, Nathan Ford, and Katharina Kranzer, "Risk factors, barriers and facilitators for linkage to antiretroviral therapy care," *AIDS*, 10 2012, *26*, 2059–2067. Cited in page 55.

Grandvoinnet, Helene, Ghazia Aslam, and Shomikho Raha, *Opening the black box: The contextual drivers of social accountability*, World Bank Publications, 2015. Cited in page 90.

Grimm, Michael and Nathalie Luck, "Can Training Enhance Adoption, Knowledge and Perception of Organic Farming Practices? Evidence from a Randomized Experiment in Indonesia,," 2020. Cited in page 47.

Haas, Andreas D., Malango T. Msukwa, Matthias Egger, Lyson Tenthani, Hannock Tweya, Andreas ıhn, Oliver J. Gadabu, Kali Tal, Luisa Salazar-Vizcaya, Janne Estill, Adrian Spoerri, Nozgechi hiri, Frank Chimbwandira, Joep J. van Oosterhout, and Olivia Keiser, "Adherence to Antiretroviral herapy During and After Pregnancy: Cohort Study on Women Receiving Care in Malawi's Option B+ rogram," *Clinical Infectious Diseases*, 7 2016, p. ciw500. Cited in page 54.

H yarimana, James, Bekezela Mbakile, and Cristian Pop-Eleches, "The Impact of HIV/AIDS and RV Treatment on Worker Absenteeism," *Journal of Human Resources*, 2010, *45*, 809–839. Cited in page 5.

H efeld, Johanna, Timothy Powell-Jackson, and Dina Balabanova, "Understanding and measuring uality of care: dealing with complexity," *Bulletin of the World Health Organization*, 5 2017, *95*, 368–374. ited in page 55.

Hanna, Rema, Sendhil Mullainathan, and Joshua Schwartzstein, "Learning Through Noticing: Theory and Evidence from a Field Experiment *," *The Quarterly Journal of Economics*, 8 2014, *129*, 1311–1353. Cited in page 23.

Harries, AD, DS Nyangulu, NJ Hargreaves, O Kaluwa, and FM Salaniponi, "Preventing antiretroviral anarchy in sub-Saharan Africa," *The Lancet*, 8 2001, *358*, 410–414. Cited in page 54.

Harrigan, P. Richard, Robert S. Hogg, Winnie W. Y. Dong, Benita Yip, Brian Wynhoven, Justin Woodward, Chanson J. Brumme, Zabrina L. Brumme, Theresa Mo, Chris S. Alexander, and Julio S. G. Montaner, "Predictors of HIV Drug-Resistance Mutations in a Large Antiretroviral-Naive Cohort Initiating Triple Antiretroviral Therapy," *The Journal of Infectious Diseases*, 2 2005, *191*, 339–347. Cited in page 54.

Hoof, Thomas J. Van, Maureen Bisognano, James L. Reinertsen, and Thomas P. Meehan, "Leading Quality Improvement in Primary Care: Recommendations for Success," *The American Journal of Medicine*, 9 2012, *125*, 869–872. Cited in page 53.

Hornbeck, Richard, "The Enduring Impact of the American Dust Bowl: Short- and Long-Run Adjustments to Environmental Catastrophe," *American Economic Review*, 6 2012, *102*, 1477–1507. Cited in page 22.

Hsiang, Solomon M., Marshall Burke, and Edward Miguel, "Quantifying the Influence of Climate on Human Conflict," *Science*, 9 2013, *341.* Cited in page 47.

Hungerman, D. and V. Moorthy, "Every Day is Earth Day: Evidence on the Long-term Impact of Environmental Activism," *American Economic Journal: Applied Economics*, 2022, *Forthcoming.* Cited in page 124.

Imhoff, Marc L., Lahouari Bounoua, Taylor Ricketts, Colby Loucks, Robert Harriss, and William T. Lawrence, "Global patterns in human consumption of net primary production," *Nature*, 6 2004, *429*, 870–873. Cited in page 27.

Ja po, Bonan, Harounan Kazianga, and Mariapia Mendola, "Agricultural Transformation and Farm- s' Expectations: Experimental Evidence from Ugand," 2020. Cited in page 47.

J , Meha, Balwinder-Singh, Preeti Rao, Amit K. Srivastava, Shishpal Poonia, Jennifer Blesh, George zzari, Andrew J. McDonald, and David B. Lobell, "The impact of agricultural interventions can be oubled by using satellite data," *Nature Sustainability*, 10 2019, *2*, 931–934. Cited in page 21.

Ja chandran, Seema, "How Economic Development Influences the Environment," *Annual Review of conomics*, 8 2022, *14.* Cited in page 23.

Ji g, H Joanna, Carlin Lockee, Karma Bass, and Irene Fraser, "Board oversight of quality: any ifferences in process of care and mortality?," *Journal of healthcare management / American College of ealthcare Executives*, 2009, *54*, 15–29; discussion 29–30. Cited in page 53.

Kamenica, Emir and Matthew Gentzkow, "Bayesian Persuasion," *American Economic Review*, 2011, *101* (6), 2590–2615. Cited 5 times in pages 92, 93, 95, 96, and 98.

Karlan, Dean, Robert Osei, Isaac Osei-Akoto, and Christopher Udry, "Agricultural Decisions after Relaxing Credit and Risk Constraints *," *The Quarterly Journal of Economics*, 5 2014, *129*, 597–652. Cited in page 47.

Kassam, A., T. Friedrich, and R. Derpsch, "Global spread of Conservation Agriculture," *International Journal of Environmental Studies*, 1 2019, *76*, 29–51. Cited in page 24.

Kastens, Jude H., J. Christopher Brown, Alexandre Camargo Coutinho, Christopher R. Bishop, and Júlio César D. M. Esquerdo, "Soy moratorium impacts on soybean and deforestation dynamics in Mato Grosso, Brazil," *PLOS ONE*, 4 2017, *12*, e0176168. Cited in page 22.

Kehoe, Laura, Alfredo Romero-Muñoz, Ester Polaina, Lyndon Estes, Holger Kreft, and Tobias Kuemmerle, "Biodiversity at risk under future cropland expansion and intensification," *Nature Ecology Evolution*, 8 2017, *1*, 1129–1135. Cited in page 22.

Kell, D. B., "Breeding crop plants with deep roots: their role in sustainable carbon, nutrient and water sequestration," *Annals of Botany*, 9 2011, *108*, 407–418. Cited in page 28.

Khan, Adnan Q., Asim I. Khwaja, and Benjamin A. Olken, "Tax Farming Redux: Experimental Evidence on Performance Pay for Tax Collectors *," *The Quarterly Journal of Economics*, 2 2016, *131*, 219–271. Cited in page 52.

_ , Asim Ijaz Khwaja, and Benjamin A. Olken, "Making Moves Matter: Experimental Evidence on Incentivizing Bureaucrats through Performance-Based Postings," *American Economic Review*, 1 2019, *109*, 237–270. Cited in page 52.

Khemani, Stuti, Ernesto Dal Bó, Claudio Ferraz, Frederico Shimizu Finan, Corinne Louise Stephenson Johnson, Adesinaola Michael Odugbemi, Dikshya Thapa, and Scott David Abrahams, "Making politics work for development: Harnessing transparency and citizen engagement," Technical Report, The World Bank 2016. Cited 2 times in pages 88 and 90.

Kondylis, Florence, Valerie Mueller, and Jessica Zhu, "Seeing is believing? Evidence from an extension network experiment," *Journal of Development Economics*, 3 2017, *125*, 1–20. Cited in page 47.

Kruk, Margaret E, Anna D Gage, Catherine Arsenault, Keely Jordan, Hannah H Leslie, Sanam Roder-DeWan, Olusoji Adeyi, Pierre Barker, Bernadette Daelmans, Svetlana V Doubova, Mike English, Ezequiel García-Elorrio, Frederico Guanais, Oye Gureje, Lisa R Hirschhorn, Lixin Jiang, Edward Kelley, Ephrem Tekle Lemango, Jerker Liljestrand, Address Malata, Tanya Marchant, Malebona Precious Matsoso, John G Meara, Manoj Mohanan, Youssoupha Ndiaye, Ole F Norheim, K Srinath Reddy, Alexander K Rowe, Joshua A Salomon, Gagan Thapa, Nana A Y Twum-Danso, and Muhammad Pate, "High-quality health systems in the Sustainable Development Goals era: time for a revolution," *The Lancet Global Health*, 11 2018, *6*, e1196–e1252. Cited in page 55.

Kubitza, Christoph, Vijesh V. Krishna, Urs Schulthess, and Meha Jain, "Estimating adoption and impacts of agricultural management practices in developing countries using satellite data. A scoping review," *Agronomy for Sustainable Development*, 6 2020, *40*, 16. Cited in page 21.

Lal, R, "Soil erosion and the global carbon budget," *Environment International*, 7 2003, *29*, 437–450. Cited in page 24.

Lal, R., "Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands," *Land Degradation Development*, 3 2006, *17*, 197–209. Cited in page 27.

_ , "Sequestering carbon in soils of agro-ecosystems," *Food Policy*, 1 2011, *36*, S33–S39. Cited 3 times in pages 22, 27, and 39.

Laloy, Eric and C. L. Bielders, "Effect of Intercropping Period Management on Runoff and Erosion in a Maize Cropping System," *Journal of Environmental Quality*, 5 2010, *39*, 1001–1008. Cited in page 21.

Lange, Markus, Nico Eisenhauer, Carlos A. Sierra, Holger Bessler, Christoph Engels, Robert I. Griffiths, Perla G. Mellado-Vázquez, Ashish A. Malik, Jacques Roy, Stefan Scheu, Sibylle Steinbeiss, Bruce C. Thomson, Susan E. Trumbore, and Gerd Gleixner, "Plant diversity increases soil microbial activity and soil carbon storage," *Nature Communications*, 11 2015, *6*, 6707. Cited in page 27.

Larson, Elysia, Godfrey Mbaruku, Redempta Mbatia, Anna Gage, Sebastien Haneuse, and Margaret Kruk, "Can investment in quality drive use? A cluster-randomised controlled study in rural Tanzania," *The Lancet Global Health*, 3 2018, *6*, S9. Cited 2 times in pages 76 and 77.

Lavy, Victor, "Evaluating the Effect of Teachers' Group Performance Incentives on Pupil Achievement," *Journal of Political Economy*, 12 2002, *110*, 1286–1317. Cited in page 52.

Lee, Jacky, Jeffrey A. Cardille, and Michael T. Coe, "Agricultural Expansion in Mato Grosso from 1986–2000: A Bayesian Time Series Approach to Tracking Past Land Cover Change," *Remote Sensing*, 2 2020, *12*, 688. Cited in page 21.

Lee, Jung-Eun and Kevin Boyce, "Impact of the hydraulic capacity of plants on water and carbon fluxes in tropical South America," *Journal of Geophysical Research*, 12 2010, *115*, D23123. Cited in page 28.

_ Benjamin R. Lintner, J. David Neelin, Xianan Jiang, Pierre Gentine, C. Kevin Boyce, Joshua B. isher, J. Taylor Perron, Terence L. Kubar, Jeonghoon Lee, and John Worden, "Reduction of tropical nd region precipitation variability via transpiration," *Geophysical Research Letters*, 10 2012, *39*, n/a–/a. Cited in page 28.

L a, Federico, Anna Prenestini, and Peter Spurgeon, "Is Management Essential to Improving the erformance and Sustainability of Health Care Systems and Organizations? A Systematic Review and Roadmap for Future Studies," *Value in Health*, 1 2013, *16*, S46–S51. Cited in page 53.

L e-Filho, Argemiro Teixeira, Britaldo Silveira Soares-Filho, Juliana Leroy Davis, Gabriel Medeiros brahão, and Jan Börner, "Deforestation reduces rainfall and agricultural revenues in the Brazilian mazon," *Nature Communications*, 12 2021, *12*, 2591. Cited in page 22.

Leite-Filho, Argemiro Teixeira, Verônica Yameê Sousa Pontes, and Marcos Heil Costa, "Effects of Deforestation on the Onset of the Rainy Season and the Duration of Dry Spells in Southern Amazonia," *Journal of Geophysical Research: Atmospheres*, 5 2019, *124*, 5268–5281. Cited in page 22.

Leoni, Eduardo, Carlos Pereira, and Lucio Renno, "Political survival strategies: Political career decisions in the Brazilian Chamber of Deputies," *Journal of Latin American Studies*, 2004, pp. 109–130. Cited 3 times in pages 89, 112, and 113.

Lobell, David B, George Azzari, Marshall Burke, Sydney Gourlay, Zhenong Jin, Talip Kilic, and Siobhan Murray, "Eyes in the Sky, Boots on the Ground: Assessing Satellite- and Ground-Based Approaches to Crop Yield Measurement and Analysis," *American Journal of Agricultural Economics*, 1 2020, *102*, 202–219. Cited 2 times in pages 25 and 26.

Lobell, David B., Stefania Di Tommaso, Calum You, Ismael Yacoubou Djima, Marshall Burke, and Talip Kilic, "Sight for Sorghums: Comparisons of Satellite- and Ground-Based Sorghum Yield Estimates in Mali," *Remote Sensing*, 12 2019, *12*, 100. Cited in page 26.

Lohmann, Susanne, "A Signaling Model of Informative and Manipulative Political Action," *American Political Science Review*, 1993, *87* (2), 319–333. Cited 2 times in pages 87 and 89.

_ , "Information aggregation through costly political action," *The American Economic Review*, 1994, pp. 518–530. Cited 2 times in pages 87 and 89.

Machado, Fabiana, Carlos Scartascini, and Mariano Tommasi, "Political institutions and street protests in Latin America," *Journal of Conflict Resolution*, 2011, *55* (3), 340–365. Cited in page 89.

Madestam, Andreas, Daniel Shoag, Stan Veuger, and David Yanagizawa-Drott, "Do political protests matter? evidence from the tea party movement," *The Quarterly Journal of Economics*, 2013, *128* (4), 1633–1685. Cited in page 89.

Mahomed, Hassan and Max O. Bachmann, "Block appointments in an overloaded South African health centre: quantitative and qualitative evaluation," *International Journal of Health Care Quality Assurance*, 7 1998, *11*, 123–126. Cited 2 times in pages 50 and 53.

Maia, Stoécio Malta Ferreira, Aldair de Souza Medeiros, Thiago Cândido dos Santos, Guilherme Bastos Lyra, Rattan Lal, Eduardo Delgado Assad, and Carlos Eduardo Pellegrino Cerri, "Potential of no-till agriculture as a nature-based solution for climate-change mitigation in Brazil," *Soil and Tillage Research*, 6 2022, *220*, 105368. Cited in page 27.

Martinez, Homero, Kartika Palar, Sebastian Linnemayr, Alexandria Smith, Kathryn Pitkin Derose, Blanca Ramírez, Hugo Farías, and Glenn Wagner, "Tailored Nutrition Education and Food Assistance Improve Adherence to HIV Antiretroviral Therapy: Evidence from Honduras," *AIDS and Behavior*, 10 2014, *18*, 566–577. Cited in page 60.

McArthur, John W. and Gordon C. McCord, "Fertilizing growth: Agricultural inputs and their effects in economic development," *Journal of Development Economics*, 7 2017, *127*, 133–152. Cited in page 23.

McConnell, K. John, Richard C. Lindrooth, Douglas R. Wholey, Thomas M. Maddox, and Nick Bloom, "Modern Management Practices and Hospital Admissions," *Health Economics*, 4 2016, *25*, 470–485. Cited 2 times in pages 52 and 75.

McDaniel, M. D., L. K. Tiemann, and A. S. Grandy, "Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis," *Ecological Applications*, 4 2014, *24*, 560–570. Cited in page 21.

Mendelsohn, Robert, William Nordhaus, and Daigee Shaw, "The Impact of Global Warming on Agriculture: A Ricardian Analysis," *American Economic Review*, 9 1994, *84*, 753–771. Cited in page 19.

Meresse, M, L March, C Kouanfack, R-C Bonono, S Boyer, G Laborde-Balen, A Aghokeng, M Suzan-Monti, E Delaporte, B Spire, M-P Carrieri, and C Laurent, "Patterns of adherence to antiretroviral therapy and HIV drug resistance over time in the Stratall ANRS 12110/ESTHER trial in Cameroon," *HIV Medicine*, 9 2014, *15*, 478–487. Cited in page 55.

Messou, Eugène, Martial Kouakou, Delphine Gabillard, Patrice Gouessé, Mamadou Koné, Amah Tchehy, Elena Losina, Kenneth A Freedberg, Thérèse N' dri Yoman, Amani Anzian, Siaka Toure, and Xavier Anglaret, "Medication Possession Ratio: Predicting and Decreasing Loss to Follow-Up in Antiretroviral Treatment Programs in Côte d'Ivoire," *JAIDS Journal of Acquired Immune Deficiency Syndromes*, 7 2011, *57*, S34–S39. Cited in page 60.

Miller, G., R. Luo, L. Zhang, S. Sylvia, Y. Shi, P. Foo, Q. Zhao, R. Martorell, A. Medina, and S. Rozelle, "Effectiveness of provider incentives for anaemia reduction in rural China: a cluster randomised trial," *BMJ*, 7 2012, *345*, e4809–e4809. Cited in page 52.

Mitchell, J. P., A. Shrestha, and S. Irmak, "Trade-offs between winter cover crop production and soil water depletion in the San Joaquin Valley, California," *Journal of Soil and Water Conservation*, 11 2015, *70*, 430–440. Cited in page 21.

Morss, Rebecca E., Jeffrey K. Lazo, Barbara G. Brown, Harold E. Brooks, Philip T. Ganderton, and Brian N. Mills, "Societal and Economic Research and Applications For Weather Forecasts: Priorities for the North American THORPEX Program," *Bulletin of the American Meteorological Society*, 3 2008, *89*, 335–346. Cited in page 25.

Muralidharan, Karthik and Venkatesh Sundararaman, "Teacher Performance Pay: Experimental Evidence from India," *Journal of Political Economy*, 2 2011, *119*, 39–77. Cited in page 52.

—, Paul Niehaus, and Sandip Sukhtankar, "Building State Capacity: Evidence from Biometric Smartcards in India," *American Economic Review*, 10 2016, *106*, 2895–2929. Cited in page 52.

Nannicini, Tommaso, Andrea Stella, Guido Tabellini, and Ugo Troiano, "Social capital and political accountability," *American Economic Journal: Economic Policy*, 2013, *5* (2), 222–50. Cited in page 112.

Nepstad, Daniel, David McGrath, Claudia Stickler, Ane Alencar, Andrea Azevedo, Briana Swette, Tathiana Bezerra, Maria DiGiano, João Shimada, Ronaldo Seroa da Motta, Eric Armijo, Leandro Castello, Paulo Brando, Matt C. Hansen, Max McGrath-Horn, Oswaldo Carvalho, and Laura Hess, "Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains," *Science*, 6 2014, *344*, 1118–1123. Cited in page 22.

Nivelle, Elodie, Julien Verzeaux, Hazzar Habbib, Yakov Kuzyakov, Guillaume Decocq, David Roger, Jérôme Lacoux, Jérôme Duclercq, Fabien Spicher, Jose-Edmundo Nava-Saucedo, Manuella Catterou, Frédéric Dubois, and Thierry Tetu, "Functional response of soil microbial communities to tillage, cover crops and nitrogen fertilization," *Applied Soil Ecology*, 12 2016, *108*, 147–155. Cited in page 21.

Northrup, Daniel L., Bruno Basso, Michael Q. Wang, Cristine L. S. Morgan, and Philip N. Benfey, "Novel technologies for emission reduction complement conservation agriculture to achieve negative emissions from row-crop production," *Proceedings of the National Academy of Sciences*, 7 2021, *118.* Cited in page 47.

Novaes, Carlos Alberto Marques, "Dinâmica institucional da representação: individualismo e partidos na Câmara dos Deputados," *Novos estudos CEBRAP*, 1994, *38* (March), 99–147. Cited in page 121.

Oliveira, R. S., L. BEZERRA, E. A. DAVIDSON, F. PINTO, C. A. KLINK, D. C. NEPSTAD, and A. MOREIRA, "Deep root function in soil water dynamics in cerrado savannas of central Brazil," *Functional Ecology*, 8 2005, *19*, 574–581. Cited in page 41.

Olken, Benjamin A., Junko Onishi, and Susan Wong, "Should Aid Reward Performance? Evidence from a Field Experiment on Health and Education in Indonesia," *American Economic Journal: Applied Economics*, 10 2014, *6*, 1–34. Cited in page 52.

Olken, Benjamin A., "Monitoring Corruption: Evidence from a Field Experiment in Indonesia," *Journal of Political Economy*, 4 2007, *115*, 200–249. Cited in page 52.

C z, Isabel, Sara Burke, Mohamed Berrada, and Hernán Cortés, "World Protests 2006-2013," *Initiative r Policy Dialogue and Friedrich-Ebert-Stiftung New York Working Paper*, 2013, (2013). Cited 2 times in ages 86 and 87.

P enti, J.-J., V. Massari, D. Descamps, A. Vabret, E. Bouvet, B. Larouze, and R. Verdon, "Predictors of irologic Failure and Resistance in HIV-Infected Patients Treated with Nevirapine- or Efavirenz-Based ntiretroviral Therapy," *Clinical Infectious Diseases*, 5 2004, *38*, 1311–1316. Cited in page 54.

P ıarelli, Francesco and Guido Tabellini, "Emotions and Political Unrest," *Journal of Political Economy*,)17, *125* (3), 903–946. Cited in page 89.

P ırson, David L., Susan Swindells, Jeffrey Mohr, Michelle Brester, Emanuel N. Vergis, Cheryl ɔquier, Marilyn M. Wagener, and Nina Singh, "Adherence to Protease Inhibitor Therapy and Outcomes in Patients with HIV Infection," *Annals of Internal Medicine*, 7 2000, *133*, 21. Cited in page 54.

Paustian, Keith, Johannes Lehmann, Stephen Ogle, David Reay, G. Philip Robertson, and Pete Smith, "Climate-smart soils," *Nature*, 4 2016, *532*, 49–57. Cited 2 times in pages 22 and 40.

Pellegrini, Adam F. A., Anders Ahlström, Sarah E. Hobbie, Peter B. Reich, Lars P. Nieradzik, A. Carla Staver, Bryant C. Scharenbroch, Ari Jumpponen, William R. L. Anderegg, James T. Randerson, and Robert B. Jackson, "Fire frequency drives decadal changes in soil carbon and nitrogen and ecosystem productivity," *Nature*, 1 2018, *553*, 194–198. Cited in page 29.

Pereira, Alan Alves, Mariangela Hungria, Julio Cezar Franchini, Glaciela Kaschuk, Lígia Maria de Oliveira Chueire, Rubens José Campo, and Eleno Torres, "Variações qualitativas e quantitativas na microbiota do solo e na fixação biológica do nitrogênio sob diferentes manejos com soja," *Revista Brasileira de Ciência do Solo*, 12 2007, *31*, 1397–1412. Cited 2 times in pages 21 and 113.

Polidoro, José Carlos, Pedro Luiz Freitas, Luís Carlos Hernani, Lúcia Helena Cunha dos Anjos, Renato de Aragão Ribeiro Rodrigues, Fernando Vieira Cesário, Aluísio Granato de Andrade, and Jefé Leão Ribeiro, “Potential impact of plans and policies based on the principles of conservation agriculture on the control of soil erosion in Brazil,” *Land Degradation Development*, 7 2021, *32*, 3457–3468. Cited in page 23.

Pomeranz, Dina, “No Taxation without Information: Deterrence and Self-Enforcement in the Value Added Tax,” *American Economic Review*, 8 2015, *105*, 2539–2569. Cited in page 52.

Rasul, Imran and Daniel Rogger, “Management of Bureaucrats and Public Service Delivery: Evidence from the Nigerian Civil Service,” *The Economic Journal*, 2 2018, *128*, 413–446. Cited in page 53.

Rattis, Ludmila, Paulo M. Brando, Marcia N. Macedo, Stephanie A. Spera, Andrea D. A. Castanho, Eduardo Q. Marques, Nathane Q. Costa, Divino V. Silverio, and Michael T. Coe, “Climatic limit for agriculture in Brazil,” *Nature Climate Change*, 12 2021, *11*, 1098–1104. Cited in page 22.

Ravindranath, N.H and M Ostwald, *Carbon inventory methods—Handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects.* 2008. Cited in page 27.

Ridgeway, Kathleen, Lisa S. Dulli, Kate R. Murray, Hannah Silverstein, Leila Dal Santo, Patrick Olsen, Danielle Darrow de Mora, and Donna R. McCarraher, “Interventions to improve antiretroviral therapy adherence among adolescents in low- and middle-income countries: A systematic review of the literature,” *PLOS ONE*, 1 2018, *13*, e0189770. Cited in page 60.

Roy, Eric D., Peter D. Richards, Luiz A. Martinelli, Luciana Della Coletta, Silvia Rafaela Machado Lins, Felipe Ferraz Vazquez, Edwin Willig, Stephanie A. Spera, Leah K. VanWey, and Stephen Porder, “The phosphorus cost of agricultural intensification in the tropics,” *Nature Plants*, 5 2016, *2*, 16043. Cited in page 20.

Rusch, Adrien, Rebecca Chaplin-Kramer, Mary M. Gardiner, Violetta Hawro, John Holland, Douglas Landis, Carsten Thies, Teja Tscharntke, Wolfgang W. Weisser, Camilla Winqvist, Megan Woltz, and Riccardo Bommarco, “Agricultural landscape simplification reduces natural pest control: A quantitative synthesis,” *Agriculture, Ecosystems Environment*, 4 2016, *221*, 198–204. Cited in page 20.

Sampaio, Gilvan, Carlos Nobre, Marcos Heil Costa, Prakki Satyamurty, Britaldo Silveira Soares-Filho, and Manoel Cardoso, “Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion,” *Geophysical Research Letters*, 9 2007, *34*, L17709. Cited in page 28.

Samuels, David J, “Pork barreling is not credit claiming or advertising: Campaign finance and the sources of the personal vote in Brazil,” *The journal of Politics*, 2002, *64* (3), 845–863. Cited in page 112.

Sangeda, Raphael Z, Fausta Mosha, Mattia Prosperi, Said Aboud, Jurgen Vercauteren, Ricardo J Camacho, Eligius F Lyamuya, Eric Van Wijngaerden, and Anne-Mieke Vandamme, “Pharmacy refill adherence outperforms self-reported methods in predicting HIV therapy outcome in resource-limited settings,” *BMC Public Health*, 12 2014, *14*, 1035. Cited in page 60.

Schacht, Caroline De, Carlota Lucas, Catarina Mboa, Michelle Gill, Eugenia Macasse, Stélio A Dimande, Emily A Bobrow, and Laura Guay, "Access to HIV prevention and care for HIV-exposed and HIV-infected children: a qualitative study in rural and urban Mozambique," *BMC Public Health*, 12 2014, *14*, 1240. Cited in page 55.

Schlenker, Wolfram and David B Lobell, "Robust negative impacts of climate change on African agriculture," *Environmental Research Letters*, 1 2010, *5*, 014010. Cited in page 22.

— **and Michael J. Roberts**, "Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change," *Proceedings of the National Academy of Sciences*, 9 2009, *106*, 15594–15598. Cited in page 22.

Schläpfer, Felix and Jon D. Erickson, "A Biotic Control Perspective on Nitrate Contamination of Groundwater from Agricultural Production," *Agricultural and Resource Economics Review*, 10 2001, *30*, 113–126. Cited in page 22.

Sethi, Ajay K, David D Celentano, Stephen J Gange, Richard D Moore, and Joel E Gallant, "Association between adherence to antiretroviral therapy and human immunodeficiency virus drug resistance.," *Clinical infectious diseases : an official publication of the Infectious Diseases Society of America*, 10 2003, *37*, 1112–8. Cited in page 54.

Shindell, Drew, Johan C. I. Kuylenstierna, Elisabetta Vignati, Rita van Dingenen, Markus Amann, Zbigniew Klimont, Susan C. Anenberg, Nicholas Muller, Greet Janssens-Maenhout, Frank Raes, Joel Schwartz, Greg Faluvegi, Luca Pozzoli, Kaarle Kupiainen, Lena Höglund-Isaksson, Lisa Emberson, David Streets, V. Ramanathan, Kevin Hicks, N. T. Kim Oanh, George Milly, Martin Williams, Volodymyr Demkine, and David Fowler, "Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security," *Science*, 1 2012, *335*, 183–189. Cited in page 29.

Silvério, Divino V, Paulo M Brando, Marcia N Macedo, Pieter S A Beck, Mercedes Bustamante, and Michael T Coe, "Agricultural expansion dominates climate changes in southeastern Amazonia: the overlooked non-GHG forcing," *Environmental Research Letters*, 10 2015, *10*, 104015. Cited in page 28.

Simoes, Rolf, Michelle C. A. Picoli, Gilberto Camara, Adeline Maciel, Lorena Santos, Pedro R. Andrade, Alber Sánchez, Karine Ferreira, and Alexandre Carvalho, "Land use and cover maps for Mato Grosso State in Brazil from 2001 to 2017," *Scientific Data*, 12 2020, *7*, 34. Cited in page 25.

Smith, Pete, Daniel Martino, Zucong Cai, Daniel Gwary, Henry Janzen, Pushpam Kumar, Bruce McCarl, Stephen Ogle, Frank O'Mara, Charles Rice, Bob Scholes, Oleg Sirotenko, Mark Howden, Tim McAllister, Genxing Pan, Vladimir Romanenkov, Uwe Schneider, Sirintornthep Towprayoon, Martin Wattenbach, and Jo Smith, "Greenhouse gas mitigation in agriculture," *Philosophical Transactions of the Royal Society B: Biological Sciences*, 2 2008, *363*, 789–813. Cited 2 times in pages 22 and 40.

Sommer, Rolf and Deborah Bossio, "Dynamics and climate change mitigation potential of soil organic carbon sequestration," *Journal of Environmental Management*, 11 2014, *144*, 83–87. Cited in page 22.

Song, Xiao-Peng, Matthew C. Hansen, Peter Potapov, Bernard Adusei, Jeffrey Pickering, Marcos Adami, Andre Lima, Viviana Zalles, Stephen V. Stehman, Carlos M. Di Bella, Maria C. Conde, Esteban J. Copati, Lucas B. Fernandes, Andres Hernandez-Serna, Samuel M. Jantz, Amy H. Pickens, Svetlana Turubanova, and Alexandra Tyukavina, "Massive soybean expansion in South America since 2000 and implications for conservation," *Nature Sustainability*, 9 2021, *4*, 784–792. Cited in page 22.

Sparovek, Gerd, Bastiaan Philip Reydon, Luís Fernando Guedes Pinto, Vinicius Faria, Flavio Luiz Mazzaro de Freitas, Claudia Azevedo-Ramos, Toby Gardner, Caio Hamamura, Raoni Rajão, Felipe Cerignoni, Gabriel Pansani Siqueira, Tomás Carvalho, Ane Alencar, and Vivian Ribeiro, "Who owns Brazilian lands?," *Land Use Policy*, 9 2019, *87*, 104062. Cited in page 30.

Spera, Stephanie A., Gillian L. Galford, Michael T. Coe, Marcia N. Macedo, and John F. Mustard, "Land-use change affects water recycling in Brazil's last agricultural frontier," *Global Change Biology*, 10 2016, *22*, 3405–3413. Cited 2 times in pages 28 and 40.

__ , Jonathan M. Winter, and Trevor F. Partridge, "Brazilian maize yields negatively affected by climate after land clearing," *Nature Sustainability*, 10 2020, *3*, 845–852. Cited 2 times in pages 22 and 28.

Spielmann, F. M., G. Wohlfahrt, A. Hammerle, F. Kitz, M. Migliavacca, G. Alberti, A. Ibrom, T. S. El-Madany, K. Gerdel, G. Moreno, O. Kolle, T. Karl, A. Peressotti, and G. Delle Vedove, "Gross Primary Productivity of Four European Ecosystems Constrained by Joint CO ₂ and COS Flux Measurements," *Geophysical Research Letters*, 5 2019, *46*, 5284–5293. Cited in page 27.

Sun, Liyang and Sarah Abraham, "Estimating dynamic treatment effects in event studies with heterogeneous treatment effects," *Journal of Econometrics*, 12 2021, *225*, 175–199. Cited in page 43.

Suri, Tavneet, "Selection and Comparative Advantage in Technology Adoption," *Econometrica*, 2011, *79*, 159–209. Cited in page 36.

Tadesse, Meron, Belay Simane, Wuletawu Abera, Lulseged Tamene, Gebermedihin Ambaw, John W. Recha, Kindu Mekonnen, Getamesay Demeke, Abebe Nigussie, and Dawit Solomon, "The Effect of Climate-Smart Agriculture on Soil Fertility, Crop Yield, and Soil Carbon in Southern Ethiopia," *Sustainability*, 4 2021, *13*, 4515. Cited in page 21.

Taylor, Charles A and Geoffrey Heal, "Fertilizer and Algal Blooms: A Satellite Approach to Assessing Water Quality," 8 2021. Cited in page 22.

Tirivayi, Nyasha, "Clinic-Based Food Assistance is Associated with Increased Medication Adherence among HIV-Infected Adults on Long-Term Antiretroviral Therapy in Zambia," *Journal of AIDS Clinical Research*, 2012, *03.* Cited in page 60.

Tsai, Thomas C., Ashish K. Jha, Atul A. Gawande, Robert S. Huckman, Nicholas Bloom, and Raffaella Sadun, "Hospital Board And Management Practices Are Strongly Related To Hospital Performance On Clinical Quality Metrics," *Health Affairs*, 8 2015, *34*, 1304–1311. Cited in page 53.

Tsakas, Elias and Nikolas Tsakas, "Noisy Persuasion," *SSRN Electronic Journal*, 2017. Cited 5 times in pages 12, 92, 95, 96, and 97.

Tscharntke, Teja, Alexandra M. Klein, Andreas Kruess, Ingolf Steffan-Dewenter, and Carsten Thies, "Landscape perspectives on agricultural intensification and biodiversity â128;147; ecosystem service management," *Ecology Letters*, 8 2005, *8*, 857–874. Cited in page 20.

Turner, Barbara J., "Adherence to Antiretroviral Therapy by Human Immunodeficiency Virus–Infected Patients," *The Journal of Infectious Diseases*, 5 2002, *185*, S143–S151. Cited in page 54.

van Groenigen, Jan Willem, Chris van Kessel, Bruce A. Hungate, Oene Oenema, David S. Powlson, and Kees Jan van Groenigen, "Sequestering Soil Organic Carbon: A Nitrogen Dilemma," *Environmental Science Technology*, 5 2017, *51*, 4738–4739. Cited in page 39.

Welch, Jarrod R., Jeffrey R. Vincent, Maximilian Auffhammer, Piedad F. Moya, Achim Dobermann, and David Dawe, "Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures," *Proceedings of the National Academy of Sciences*, 8 2010, *107*, 14562–14567. Cited in page 22.

Williams, Alwyn, Nicholas R. Jordan, Richard G. Smith, Mitchell C. Hunter, Melanie Kammerer, Daniel A. Kane, Roger T. Koide, and Adam S. Davis, "A regionally-adapted implementation of conservation agriculture delivers rapid improvements to soil properties associated with crop yield stability," *Scientific Reports*, 12 2018, *8*, 8467. Cited 2 times in pages 21 and 24.

Wätzold, Frank, Martin Drechsler, Karin Johst, Melanie Mewes, and Astrid Sturm, "A Novel, Spatiotemporally Explicit Ecological-economic Modeling Procedure for the Design of Cost-effective Agri-environment Schemes to Conserve Biodiversity," *American Journal of Agricultural Economics*, 3 2016, *98*, 489–512. Cited in page 22.

Xu, Chonggang, Nate G. McDowell, Rosie A. Fisher, Liang Wei, Sanna Sevanto, Bradley O. Christoffersen, Ensheng Weng, and Richard S. Middleton, "Increasing impacts of extreme droughts on vegetation productivity under climate change," *Nature Climate Change*, 12 2019, *9*, 948–953. Cited in page 27.

Zabel, Florian, Ruth Delzeit, Julia M. Schneider, Ralf Seppelt, Wolfram Mauser, and Tomáš Václavík, "Global impacts of future cropland expansion and intensification on agricultural markets and biodiversity," *Nature Communications*, 12 2019, *10*, 2844. Cited in page 22.