# Essays in Development Economics and Economic History

by

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# Acknowledgments

This thesis is for nonno Mario. With the unfortunate event of his illness, I realised how strong our family is. Now I know whom to thank for the resilience I found in myself during these long six years:

It's nonno and nonna, one enduring his degenerating body singing the Anthem, the other remaining strong at the bedside of her husband.

It's dad, who set the example on how to be a self-made person, and inspired my brother and me to build our own path, despite the easy ways out.

It's above all mum, who carried on her shoulders the burden of a decaying father, the numbness of an old mother, the heartbreaking distance with her children. You hold up two families mum: the one you come from and the one you created. Thank you for showing me your strength, and for teaching me that real strong people are the more human and simple ones.

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No Chinta, Do Furti.

# Declarations

This thesis is submitted to the University of Warwick in accordance with the requirements of the degree of Doctor of Philosophy. I declare that any material contained in this thesis has not been submitted for a degree to any other university. Chapter 1 is my own, single-authored work. Chapter 2 is collaborative work with Luigi Pascali. Chapter 3 is collaborative work with Kristina Czura and Andreas Menzel.

Martina Miotto

# Abstract

This thesis consists of three chapters. Each chapter can be read as an independent piece of research, since the topics studied are different in nature and in the methodologies applied. However, all chapters delve into topics of development economics, looking at it from an historical perspective, as in Chapters 1 and 2, or from a contemporary policy perspective, as in Chapter 3.

In the first chapter, I study the impact of European colonialism in Africa on the present status of women. The historical literature suggests that a critical determinant of persistent gender inequality is the colonial cash crop system. This favoured men's entry into the cash economy and excluded women, whose workload increased as they provided additional labour in their husbands' cash crop fields. By contrast, contemporary economic literature suggests that raising the status of women in the labour force could improve gender norms. I take districts with different levels of participation in cash crop agriculture and compare outcomes for the contemporary female descendants, using exogenous land suitability as the instrument for cash crop production. My findings show a persistent positive effect of cash crop agriculture on women's status, measured as higher agency within the household and less willingness to justify husbands' violence. The intergenerational transmission of culture plays a key role in explaining the long-run persistent effect, which is especially prevalent in regions whose cash crops were cocoa and palm oil.

In the second chapter, a collaboration with Luigi Pascali, we show that navigation patterns and ship speed changed as a result of the adoption of the chronometer, a tool invented to precisely measure longitude at sea. Combining historical data on navigation for the period 1750-1855 with climatological data on cloud coverage, we find that navigation changed around the years 1825-1834, the decade in which most historical sources place the mass diffusion of the chronometer. We find that ships became faster in more overcast areas when using the chronometer, as they did not need to rely on celestial navigation when using the chronometer. As sailing speed reduction contributed to the transport revolution of the nineteenth century, this paper quantifies how this technology contributed to this process.

Finally, in the third chapter, which is joint with Kristina Czura and Andreas Menzel, we present the results of a randomised controlled trial (RCT) we conducted on a sample of 1,000 female garment workers in three factories in Bangladesh, offering access to free sanitary pads at work to 500 of the workers. We cross-randomised participation in information sessions for hygienic menstrual health care implemented by an experienced local NGO, and we vary the salience of commonly perceived taboos in the pad collection process. We find effects of the free pads and information sessions on self-reported pad use, but not of the taboo variations. We find effects on absenteeism and adherence to traditional restrictive and health-adverse taboos surrounding menstruation, but not on worker turnover or self-reported well-being at work.

# Chapter 1

# Colonialism, Cash Crops and Women in Africa

I thank Sascha Becker, James Fenske, Bishnu Gupta and Andreas Menzel for their valuable comments, as well as the participants of the following seminars and workshops: Applied Micro Early Stage (Warwick), African Economic History Network (Bologna), Brown Bag Seminar (Prague), Economic History Society (Belfast), Graduate Seminar in Economic History (London), Workshop on Gender and Family in the Labor Market (Prague), Graduate Seminar in Economic and Social History (Oxford). I also thank Maria Fibaek for sharing data and useful discussions. I gratefully acknowledge the financial support of the ESRC.

## 1.1 Introduction

Empowering women is a fundamental development objective, and is essential to enabling women and men to participate equally in society and in the economy.[1] Gender inequalities are pervasive and present along a multitude of dimensions, such as levels of education, labour market participation rates, and political representation.[2] To measure them, the United Nations Development Programme has developed two indices: the Gender Development Index and the Gender Inequality Index.[3] Figures 1.1 and 1.2 show their distribution around the world, revealing two patterns: overall, women score worse than men, and the majority of low-performing countries are ex-colonies, with a stark cluster in Africa.

A recent and growing empirical literature focuses on the historical roots of gender norms and female empowerment. There is a large set of evidence in this literature that links historical conditions to present gender inequalities (among others, Alesina et al. (2013); Henderson and Whatley (2014), Giuliano and Nunn (2018)). The consensus of this research is that differences in cultural norms regarding gender roles emerge in response to specific historical situations, and tend to persist even after the historical conditions have changed (Giuliano (2017)).

I study the role of the colonial agricultural system, based on cash crop production, in shaping gender norms and women's empowerment in Sub-Saharan Africa. This system was biased towards African men, making them the primary beneficiaries of the economic returns, but dependent upon women's unremunerated work (Boserup (1970), Etienne (1977), Korieh (2001)).

The historical and anthropological literatures have long suggested that women's subordinate position in the cash economy harmed their socio-economic status (Boserup (1970), Rodney (1972), Davison (1988), Grier (1992)). Beyond their duties in the household and in food crop production, women's workloads increased as they were needed to provide additional labour in their husbands' cash crops. However, it is

[1]Source: World Bank, 2014: www.worldbank.org/en/region/afr/brief/improving-gender-equality-in-africa.

[2]UN, Gender statistics: https://genderstats.un.org/#/indicators.

[3]The Gender Development Index measures gender gaps in human development achievements by accounting for disparities between women and men on three basic dimensions of human development: health, measured as life expectancy at birth, knowledge, measured as expected and mean years of schooling, and living standards, measured as the gross national income per capita. It is the ratio of the Human Development Indices calculated separately for females and males. The Gender Inequality Index measures gender inequalities in three important aspects of human development: reproductive health, measured by the maternal mortality ratio and adolescent birth rates, empowerment, measured by proportion of parliamentary seats occupied by females and proportion of adult females and males aged 25 years and older with at least some secondary education, and economic status, expressed as labour market participation and measured by the labour force participation rate of female and male populations aged 15 years and older (http://www.undp.org).

not clear whether this hypothesis is consistent with contemporary economic evidence. Since cash crop agriculture often increased female labour in agriculture, as more output was required to meet colonial taxation demands, recent empirical literature on the determinants of gender inequality would suggest that this led to better outcomes for women, and that these could persist into the present (Alesina et al. (2013), Hansen et al. (2015), Teso (2018)). My results support this second view, that women are better off as a consequence of their greater traditional involvement in cash crop agriculture.

I construct a dataset linking three sets of information: (i) current indicators for women's empowerment, using variables from the Demographic and Health Surveys, (ii) ancestral location and characteristics of the ethnicities of the women in the data from Murdock's (1967) Ethnographic Atlas, and (iii) the location of cash crop production in colonial times. I retrieved yearly cash crop production data for the twenty years between 1920 and 1940 from historical colonial official statistics, complemented with historical maps of cash cropping areas when yearly data was not available. With these data, I compare the current status of women whose ancestors lived in colonial districts more involved in cash crop agriculture with women whose ancestors lived in districts less or not at all involved in cash crop agriculture. I control for pre-colonial levels of women's empowerment using ethnicity-level variables from the recent economic literature. However, as colonial cash crop production could be endogenous to unobserved characteristics of local populations, I instrument for colonial cash crop production with terrain suitability for cash crops, relative to suitability for food crops.

I find that women whose ancestors were more involved in cash crop production are nowadays more empowered: they have more decision-making power within the household and they are less willing to justify their husband's violence. Men from the same ancestral areas are also less keen to condone spousal violence, in line with improved gender norms, but do not display more empowerment in terms of household agency.

I explore possible mechanisms for the positive results on women's status. I find that on average the long lasting impact of cash crop agriculture is visible also in higher education levels for women but not in labour force participation, suggesting that the higher education levels are not driven by labour market opportunities. I find a larger effect on decisions that do not involve financial matters such as income management or purchases for the house. Women have greater agency over their own income but not their husbands'. Further, I examine whether the effect of cash crop agriculture is driven by certain specific cash crops. I show that the results are mainly driven by cocoa and palm oil. Indeed, the historical literature suggests a particularly active role for women in the production of cocoa and palm oil (Grier (1992), Austin (2014)), speaking further to the hypothesis that the increased need for female labour in cash crop production lead to their persistent empowerment. I also explore the role of the marriage market in the long-run transmission of cultural values (Fernández et al. (2004)), without finding significant evidence in support of this channel.

This paper contributes to several strands of literature. First, it complements a growing empirical literature on the historical roots of gender roles. In particular, this paper contributes to a literature on natural experiments, which claims that historical shocks can alter beliefs about the role of women and that these are transmitted across generations. For instance, the Transatlantic slave trade has been shown to affect current female labour force participation (Teso (2018)), and the acceptability of polygyny (Edlund and Ku (2011), Dalton and Leung (2014)). Acemoglu et al. (2004), Fernández et al. (2004) and Goldin and Olivetti (2013) show that higher mobilization rate of men during World War II, leads to a positive and persistent effect on female labour force participation in the United States. Becker and Woessmann (2008) look at the long-term impact of the Protestant Reformation and show it decreased the gender gap in basic education and literacy. Campa and Serafinelli (2019) document how more equal gender-role attitudes emerged in state-socialist regimes. Xue (2018) finds that premodern cotton textile production is systematically correlated with more progressive gender norms and daughter preference. Grosjean and Khattar (2018) study the long-run effect of the male-biased sex ratio that emerged in Australia by the late eighteenth century, finding worse outcomes on cultural attitudes and women's labour supply decisions in areas with historically more male-biased sex ratios. I complement this literature by focusing on another historical shock, namely the introduction of cash crop production by European colonisers on the African continent. Also, at the centre of this paper are two measures of women's empowerment rarely used in the literature so far, which inform us how women perceive their status rather than measuring it through standard objective indicators, such as labour force participation or education. The results show that, even if women from areas more involved in cash crop production do not participate more in the labour force, they do display higher levels of empowerment by having more decision power and justifying husbands' violence in fewer instances.

Second, this paper contributes to the debate on colonialism and women's status, which spans different fields including economic history, history and anthropology. A major avenue of research that links colonialism and gender norms looks at the role played by Christian mission education. Among others, Boserup (1970), Rodney (1972), and Akyeampong and Fofack (2014) suggest that Christian mission schools provided gender-biased education, reflecting the typical Western view of the domestic role of women, disproportionally teaching males knowledge useful for participation in the modern colonial economy and leading to sizeable gender gaps in education (Nunn (2014), Meier zu Selhausen and Weisdorf (2016), De Haas and Frankema (2018)). Other studies have instead argued that a channel through which colonialism affected women's status is the decline in land control and use rights for women. This process could take various forms. It could be institutionalised, as happened in Rhodesia with the Native Land Husbandry Act of 1951, which gave male heads of household individual, rather than lineage, rights to land (Peters and Peters (1998)). Or it could occur as a consequence of land becoming scarce and hence more expensive, making it less affordable to African women (Sheldon (2017)). I contribute to this research by providing the first quantitative test of the prominent cash crop hypothesis, complementing the evidence based on qualitative methods from the anthropology and historical literatures. I do so by exploiting geographical, within-country variation in cash crop production within colonies, using within-country variation in soil suitability for cash crops for identification, and large-scale representative surveys of country populations.

In the next section I outline the historical background, describing pre-colonial gender norms and the introduction of cash crops in Africa. In section 3, I outline the two competing hypotheses discussed in this paper. I give a detailed description of the data used for the analysis in section 4, and I lay out the empirical strategy and construct the instrument for cash crop production in section 5. In section 6, I focus on the main results, investigating the effect of cash crop agriculture on women's status, while in section 7, I explore the mechanisms. In section 8, I present robustness checks, and in section 9 the conclusion.

## 1.2 Historical Background

### 1.2.1 Pre-colonial Gender Roles

Gender relations and women's status in pre-colonial Africa differed across societies and are difficult to lay out in detail. The anthropologist Sudarkasa (1986) argues that the "status of women" as a connotation of sexual stratification is not appropriate for describing the relationship between female and male in most precolonial African societies. Citing Whyte (1978), she suggests that in many indigenous African societies women and men occupied different domains, the domestic and the public one, and these should not be understood in terms of ranking but rather as equally important and mostly overlapping. Sudarkasa (1986) stresses that it was the market economy introduced at the onset of colonisation that created conditions for increasingly defining females and males as unitary distinct categories that were compared one against the other and, therefore, hierarchically related to one another.

Bearing in mind these limitations on the use of the term "status" when addressing pre-colonial gender relations, anthropologists and historians have generally reached a consensus that women played important roles in rites associated with religious beliefs (Sheldon (2017)), had a degree of control over resources (Etienne (1977), Guyer (1980)), that they were involved in the political process and the public domain (Sudarkasa (1986)), organized themselves into secret societies and organizations (Sheldon (2017)), held formal leadership and elevated roles in many matrilineal societies (Guyer (1980), Sudarkasa (1986), Grier (1992), Henderson and Whatley (2014)), and were involved in the production and distribution of various goods, with their activities complementary rather than subordinate to those of men (Etienne (1977), Sudarkasa (1986), Tashjian and Allman (2002)).[4]

In particular, discussing the role of women in agriculture during pre-colonial times, Boserup (1970, p.16), claims that "Africa is the region of female farming *par excellence*", and there are many accounts of women in agriculture spending at least as many hours in the fields as men did (Boserup (1970), Henn (1978), Linares (1985)). Meanwhile women were often entitled to appropriate the harvests of particular crops, either because they were the primary producers of such crops (Etienne (1977)) or because of land rights in matrilineal societies (Coquery-Vidrovitch (1997), Tashjian and Allman (2002)).[5]

### 1.2.2 Cash Crops and Colonisation

Cash crops are crops grown mainly for an export market, and are different from food crops that are used for subsistence and are only occasionally sold for cash (Klein (1980), Hart et al. (1982), Bates (1983)). The introduction of the first cash crops in Africa, other than the few native ones such as palm oil and kola, and

[4] Sheldon (2017) argues that Africa was the world region that was most noted for a high incidence of matrilineal descent systems, found in an extensive belt across the centre of the continent, and including peoples in parts of West Africa, central Africa, and extending into southern Africa.

[5] Coquery-Vidrovitch (1997) states that in the matrilineal tradition marital dominance was counterbalanced by women's continuing to belong to their own lineage of origin, and that before colonisation no distinction was made between the male right to allocate familial lands, which were not private, and the mixed right of access to the land to which women acceded as daughters, wives, and mothers. Looking at the context of pre-colonial Asante, Tashjian and Allman (2002) claim that although spouses jointly produced foodstuff, joint labour did not give rise to joint property, and as was the case for most matrilineal societies, property was owned by one spouse or the other.

the resulting emergence of mass export agriculture began in the nineteenth century, before the European Scramble of Africa, primarily along the coasts. However, it was during colonial rule that agricultural-export economies expanded and incorporated the fertile hinterlands (Austin (2009)) under the pressure of colonial administrations, which encouraged market-oriented crop production by both persuasion and coercion (Usoro (1977), Ochonu (2018)).

Cash crops usually had a sole economic function, different from food crops, which tended to have social uses, as in ceremonies for instance, and to take on diverse meanings in different local contexts. They were frequently foreign in origin and lacked social meaning in particular kinship contexts.[6] This facilitated sexual and social separation of agricultural tasks once the new crops were introduced (Linares (1985)).

## 1.3 Hypotheses: Cash Crops and Gender Norms

According to the historical and anthropological literatures, women's exclusion from the growing colonial cash economy had a negative and persistent effect on their status. Their marginalization can be thought of as the outcome of few combined forces.

Colonial states introduced monetization in Africa in the form of monetary wage payments and monetary tax collection.[7] The tax system was introduced with the main purpose of making colonies financially self-sufficient. Colonial officials created either a flat-rate hut tax on African dwellings or a poll tax paid mostly by African men.[8] This tax system implicitly considered the man as the head of the household, and hence the only responsible for tax payments of the whole household, imposing the coloniser's idealized notion of women's dependent status on men (Byfield (2018)). It was based on the European model, where the husband and father

[6] For instance, cotton was introduced to Ghana by the British administration from 1903 onwards (Meier zu Selhausen (2015)); Groundnuts were introduced to Senegal by the French (Linares (1985)); Cocoa was introduced to Ghana by British missionaries in the 1860s (Hill (1963)) and to the Ivory Coast by the French in 1910 (Ruf (1995)); Tobacco was introduced to South Africa by Jehovah's Witnesses at the beginning of the twentieth century (Coquery-Vidrovitch (1997)).

[7] Rudimentary currencies were already used throughout the continent, however, colonial states outlawed pre-colonial standards of value and currencies such as manilla, cowrie shells, metal bars, cloth, and others, in favour of unified official currencies within sovereign states and their colonies and protectorates (Ochonu (2018)).

[8] In the vast majority of cases taxes were imposed on African dwellings or men. As the imposition of taxation was heterogeneous across and within countries, there were exceptions. For instance, the colonial government in Nigeria initially imposed taxation on African women as well, however, after the Abeokuta Women's Revolt in the 1940s, women were excluded from taxation. In Ghana, direct taxation was not imposed until the 1950s (Sederberg (1971), Frankema and van Waijenburg (2013)).

was considered the head of the household and responsible for paying taxes, and for the other interactions with the state (Sheldon (2017)).

Even though households were not formally obliged to cultivate cash crops, the fiscal pressure of the newly introduced tax system indirectly forced farmers and peasants to market their produce and therefore to maximize their production of cash crops (Bryceson (1990), Mandala (1990), Wrigley (1959), Papaioannou and de Haas (2017)). While these crops assumed a monetary value, men quickly assumed control over their production, land and especially over their profits. This process was the result of two forces. First, because of the patriarchal assumption about the appropriate role of women, colonial officials dictated agricultural development policies that enabled men to dominate the cultivation of cash crops for the international market (Korieh (2001)), and only recognised men as counterparts in their transactions (Hailey and Hailey (1957)). Second, as the primary target of taxation men had to acquire cash, tending to justify and reinforce their control over cash crops (Etienne (1977)), and leading to women's exclusion from the cash economy. Boserup (1970) argues that European settlers and colonial administrators neglected the female agricultural labour force when they introduced modern commercial agriculture, and promoted the productivity of male labour.

The exclusion of women from taxation, however, did not imply an exclusion from the work involved in cash crop production. In most cases women continued to work alongside their husbands to produce valuable crops, which was an extension of domestic chores, while their husbands became the owner of the land and profits from cropping (Etienne (1977), Guyer (1980), Davison (1988), Grier (1992), Coquery-Vidrovitch (1997)). Cash crop production required extra labour of women, as they also continued to play a critical role in subsistence agriculture, from which men abruptly withdrew. Although essential, mediated by cash and the capitalist commodity economy, their labour became invisible and largely unremunerated (Etienne (1977), Byfield (2018)).

However, it is not clear whether this hypothesis from the historical and anthropological literatures is consistent with contemporary economic evidence. If cash crop agriculture increased female labour in agriculture because additional income was needed to pay taxes, recent empirical literature on the determinants of gender inequality would suggest that this may lead to better outcomes for women. For instance, Teso (2018) demonstrates that the shortage of African men in areas more severely affected by the Transatlantic slave trade pushed women into the labour force, substituting missing men on new areas of work. He finds positive long-term effects both on current labour participation and attitudes towards women. On the opposite side, Alesina et al. (2013) show that descendants of societies that traditionally practised plough agriculture, where men had a physical advantage in farming and women were therefore less involved in agricultural work, today have less equal gender norms, and less female participation in the workplace, politics, and entrepreneurial activities. Hansen et al. (2015) find that societies with long histories of agriculture show greater dissimilarity in gender roles as a consequence of more patriarchal values and beliefs regarding the proper role of women in society. They argue that one of the primary mechanisms underlying their results is that societies with longer agricultural histories had a higher level of technological advancement, which in the Malthusian Epoch translated into higher fertility and a diminished role for women outside the home.

## 1.4 Description of Data

The analysis in this paper is based on a cross-sectional dataset covering roughly 103,100 present-day African women across the ex-British colonies of current Ghana, Kenya, Malawi, Nigeria, and Uganda.[9] The dataset links three sets of information: current indicators for women's empowerment, ancestral characteristics of their ethnicities, and cash crop production in the ancestral homelands of these ethnicities in colonial times. This section outlines the data sources and the process of constructing the main variables.

### 1.4.1 Modern Variables

#### Main Outcomes

The main outcome variables are derived from the Demographic and Health Surveys (DHS). I use all rounds for many ex-British colonies from the year 2000 onwards, when additional indicators on women's status and empowerment were included in the surveys.[10] The DHS data were collected by a stratified two-stage cluster design that is meant to provide a representative sample of women aged 15-49 at national and state levels. I construct two main outcome variables capturing women's empowerment, which I refer to as the *Beating Free Index* and the *Decision Index*.

The *Beating Free Index* is the sum of answers to a series of yes/no questions where women respondents are asked whether a husband is justified in hitting or

[9]My sample does not include women from the remaining ex-British colonies as I have not yet collected the data on the main explanatory variable.

[10]DHS Survey rounds used for the main results: Ghana 2003, 2008, 2014; Kenya 2003, 2008, 2014; Malawi 2000, 2004, 2010, 2016; Nigeria 2003, 2008, 2013; Uganda 2001, 2006, 2011, 2016. All DHS survey data have been retrieved already harmonized from IPUMS-DHS.

beating his wife under a number of different circumstances, that are: the wife goes out without telling him, the wife neglects their children, the wife argues with him, the wife refuses to have sex with him, the wife burns the food. The index is the share of times a woman replies “No” to these questions. Thus, a higher value on this index means that women do not justify beating in a larger set of circumstances, and are therefore more empowered. Table 1.1 summarises the availability of the index components across surveys. To minimize misreporting, I do not include survey respondents who were in the same room as their husband when being asked these questions. The beating justification variables have already been used in previous economics literature on violence against women, such as in Alesina et al. (2016), Leyaro et al. (2017) and Teso (2018).

The *Decision Index* is constructed in a similar way, and provides information on whether women report to have some say on: making large household purchases, household purchases for daily needs, visits to family or relatives, spending their own earnings, spending husband’s earnings, their own health care, food to be cooked, and children’s health care. The possible answers to these questions are *woman alone, woman and husband/partner, woman and someone else, husband/partner, someone else*. The decision variable on these situations takes value of 1 whenever a woman has some degree of say in a decision (first three options) and 0 otherwise (last two options). The *Decision Index* then gives the share of decisions’ dimensions for which the woman has some input. Table 1.2 summarises the availability of the index components across surveys. Decision making power has been widely used in the literature to measure women’s empowerment, as reviewed in Duflo (2012), and these DHS variables have also recently being used in Teso (2018) to look at gender norms. I focus on the *Beating Free* and *Decision* indices as they most probably provide insights on an intrinsic dimension of female empowerment that is not endogenous to market forces, and therefore capture an uncontaminated measure of status.

### Additional Outcomes

To further explore mechanisms, I use years of education and labour force participation as additional outcome variables. While in some cases these may be measurable with more precision, they should not be interpreted as pure indicators of empowerment, as they are also determined by different market forces and other variables such as poverty and safety.

Table 1.3 provides summary statistics for all the outcome variables used. On average, women do not justify beating in three-fourths of the occasions, have some decision power in slightly more than a half of the cases, have on average 6 years of education, and the majority of them are currently working.

### 1.4.2 Ethnicity Level Data

To measure women pre-colonial status, I use information on ancestral anthropological and cultural practices of the women's ethnic groups, taken from Murdock's (1967) Ethnographic Atlas. The Ethnographic Atlas is an ethnicity-level database with pre-colonial information for more than 1,200 ethnic groups worldwide. To control for women's empowerment during pre-colonial times I use many of the variables that the previous economic and anthropological literature has used regarding women's status or value.

In particular, I use data on customs of bride price, practice of polygyny, the descent system of matriliny, and on whether agriculture is the main subsistence source for an ethnicity's economy. Appendix A lists how I code these variables starting from the original variables in the Ethnographic Atlas.[11]

Linking DHS respondents to their ancestors' ethnic groups in the Ethnographic Atlas is not straightforward, as ethnicities' names can vary across space and time. In order to address this, I use different sources: the Ethnologue, a catalogue of more than 6,700 languages spoken in 228 countries, the Joshua Project, an online directory of more than 10,000 ethnic groups, and the Ethnohistorical Dictionary, a book with information on more than 1,800 different ethnic societies.[12] These sources provide alternative names for ethnicities and specify links among societies (based on location or supergroup), making it possible to connect distinct names in the DHS surveys and the Ethnographic Atlas. When no match is found, I use pre-existing matches from two datasets provided, respectively, by Nunn and Wantchekon (2011) and Fenske (2014). To fill a small remaining gap I checked on further online sources

[11] *Bride price* can be considered capturing an implicit economic value of women following Boserup (1970), Goody (1973), Becker (1981), Alesina et al. (2016); *Polygyny* is a practice which generally correlates negatively with female bargaining power (Tertilt (2005), Doepke et al. (2012)) since having more than one wife customarily indicates less progressive attitudes and a lower consideration of women's status (Alesina et al. (2016)); *Matrilineal system of descent* is associated with a higher status of women in different sources as Guyer (1980), Grier (1992), Henderson and Whatley (2014), Sheldon (2017); *Agriculture as main subsistence activity* can reflect a higher status of women, as discussed in Alesina et al. (2016), since in economies based on agriculture, especially without the plough like basically everywhere in Africa, women could participate more in the labour force and develop a more equal status in society and in the family. Alesina et al. (2013) relate prevailing gender norms to aboriginal use of plough and finds strong evidences that descendants of societies which traditionally practised plough agriculture have today less equal gender norms. However, there is no society in my sample which practised plough agriculture before colonial times, reflecting the general trend for African societies present in the Murdock's Atlas.

[12] Ethnologue: https://www.ethnologue.com; Joshua Project: https://joshuaproject.net; Ethnohistorical Dictionary: Olson (1996).

for possible matches.[13] Overall, 64 percent of women in the final sample are linked to an ethnicity in the Atlas through a perfect match, 32 percent through Ethnologue, Joshua Project or the Ethnohistorical Dictionary, more than 3 percent thanks to pre-existing mappings, and less than 0.5 percent via manual matching.[14]

### 1.4.3 Colonial Agricultural Production

To measure colonial agricultural production, I use an indicator for the share of a colonial district's area dedicated to cash crops. Following the definition by Papaioannou and de Haas (2017) I classify the following as cash crops: cocoa, coffee, copra, cotton, groundnuts, palm oil and tobacco.

Based on borders of colonial districts from historical maps, I measure the share of the total districts' area that was under cash crops cultivation. I compiled data on colonial agricultural production from a number of different sources, depending on the availability of reliable information. Whenever official colonial statistics are available, I collected and digitised acres under cultivation of each cash crop for all colonial districts at yearly level over the period 1920-1939. I retrieved from the same sources total districts' areas, and averaged agricultural production across these years. Whenever official accounts are not available, I extract similar information from historical maps showing the main cash crops production zones. Appendix B lists all the sources used to compile the agricultural production data. These data are collected for all the countries of residence of the women in my sample, and also for current-day Tanzania, as many respondents' ancestors lived there.

### 1.4.4 Data on Terrain Suitability

I use data on terrain suitability for the cultivation of different crops to provide a source of exogenous geographic variation in colonial cash crop agriculture.[15] Data on suitability are provided by the Global Agro-Ecological Zones (GAEZ) project from the Food and Agriculture Organization (FAO).[16] The FAO-GAEZ data provide

[13]The match is performed either on ethnicities' names, or on the language spoken by an ethnicity.

[14]For almost 80 percent of the sample the match is either perfect or the listed names in the DHS and the Ethnographic Atlas are alternative names for the same ethnicity. For example, a substitute name for the Mole-Dagbani of Ghana is Dagomba, and in the same country, Twi and Ashanti are two different names to refer to the same ethic group. For the remaining part of the sample ethnicities are linked to their supergroup or a related group. For instance, the Baruli of Uganda are matched to the Ganda, a larger group of which they form a smaller part.

[15]I use all crops available in the FAO-GAEZ database and divide them in two categories: cash crops (cocoa, coffee, copra, cotton, groundnuts, palm oil, tobacco) and all remaining as food crops (banana, cassava, foxtail and pearl millet, maize, phaseolu beans, dry and wet rice, sorghum, sweet and white potato, sugar beet, sugar cane, wheat).

[16]http://www.fao.org/nr/gaez.

global estimates of land suitability for different crops within cells of approximately fifty-six kilometres by fifty-six kilometres, based on land and climate characteristics. The climate characteristics are precipitation, frequency of wet days, mean temperature, diurnal temperature range, vapour pressure, cloud cover, sunshine, ground-frost frequency, and wind speed, and they all come from the global climatic database compiled by the Climate Research Unit at the University of East Anglia. Land characteristics are taken from the FAO's Digital Soil Map of the World. The final FAO-GAEZ dataset provides an estimate of the potential yield (kg/ha) of each crop in each grid-cell, given an assumed level of water supply and input use, and then creates a suitability index that ranges from 0 to 1. To closely mimic historical land conditions and agriculture during colonial rule, I use variables constructed under the assumption that cultivation occurs under rain-fed conditions and low input intensity.

### 1.4.5 Other Data

I collect additional data from various sources to control for further characteristics of colonial districts and ethnicities. For ethnic ancestral homelands, I retrieve information on distance from rivers and the coast from the Natural Earth dataset, distance from the closest railway track using maps available in Jedwab and Moradi (2016), and on the number of slaves involved both in the Transatlantic and the Indian slave trade using Nunn and Wantchekon (2011) data. At the colonial district level I combine a host of historical data: on population density in 1930 from the Historical Database of the Global Environment; on the historical rule of Islam by geocoding a 1918 map of the geographic distribution of religions in Africa from Bartholomew and Brooke (1918); on conflicts occurring before colonisation between 1400 and 1700 from Brecke (1999); on the dominant vegetation type using White's (1983) map; on the number of Christian missions from Roome (1925); on soil ruggedness using Nunn and Puga's (2012) data; on the presence of diamond mines from Lujala et al.'s (2005) DIADATA dataset. I also gather data on general land quality using nutrient availability and land workability provided by FAO, nitrogen and carbon density level taken from EarthDATA Spatial Data Access Tool, and an index for general suitability developed by Ramankutty et al. (2002). A full list of all variables used in the analysis along with detailed information on sources can be found in Appendix A.

## 1.5 Empirical Strategy

### 1.5.1 Baseline Estimating Equation

To measure the persistent effect of colonial cash crop production on current-day women's status I estimate the following equation:

$$EMP_{iedcy} = \alpha + \beta CP_d + I_{iedcy}\gamma + E_e\delta + D_d\lambda + \rho_{cy} + \varepsilon_{iedcy} \tag{1.1}$$

where $EMP_{iedcy}$ is women's empowerment status, measured either through the *Beating Free Index* or the *Decision Index* for individual $i$ of ethnicity $e$ with ancestors living in district $d$ for DHS country $c$ administered in year $y$. $CP_d$ denotes intensity in cash crop production in the ancestral colonial district, reducing concerns about possibly endogenous post-colonial migration.[17] $I_{iedcy}$, $E_e$, $D_d$ are, respectively, contemporary individual level controls, ethnicity level controls, and ancestral district level controls. Furthermore, I include fixed effects at DHS country-round level $\rho_{cy}$.[18] Standard errors are robust and clustered at ethnicity level. In Table 1.11 of Appendix C, I show that the main results are robust using standard errors adjusted for two-way clustering within ethnic group and district of origin.

### 1.5.2 Instrument for Cash Crop Agriculture

Cash crop production may be endogenous. For instance, ethnicities more likely to engage with Europeans in cash crop agriculture could also be those with particularly regressive gender norms, matching those of the colonisers. On the other hand, ethnicities with more inclusive gender norms could be more open to cooperation with colonisers. In either case, OLS estimates of $\beta$ in equation 1.1 would be biased. Another potential concern is that the data on colonial cash crop production is derived from official colonial statistics and historical maps. This might generate measurement error that could bias OLS estimates towards zero. To deal with these concerns, I use the relative suitability of land for cash crops compared to food crops as an instrument for colonial cash crop agriculture. I take the ratio of average suitability for all cash crops over average suitability for all cash and food crops at the

[17] Ancestral colonial districts are referred to as the district where a respondent's ancestors lived during colonial rule. Such districts are geographically different from current ones, as districts' borders changed with time.

[18] Results are robust to adding origin country-by-ethnicity fixed effects.

colonial district level:

$$SuitCC_d = \frac{\frac{1}{C}\sum_{c=1}^{C} Suit_{cd}}{\frac{1}{C}\sum_{c=1}^{C} Suit_{cd} + \frac{1}{F}\sum_{f=1}^{F} Suit_{fd}} \tag{1.2}$$

where $c = 1, .., C$ and $f = 1, .., F$ are cash and food crops. Therefore, I estimate the first stage as:

$$CP_d = \alpha + \beta SuitCC_d + I_{iedcy}\gamma + E_e\delta + D_d\lambda + \rho_{cy} + \upsilon_{iedcy} \tag{1.3}$$

**Identifying Assumptions and Instrument Validity**

The key identifying assumption is that the instrument needs to be uncorrelated with the error term in equation 1.1, $\varepsilon_{iedcy}$, to satisfy the exclusion restriction. That is, suitability for cash crops should predict contemporary women's empowerment only via the channel of agricultural production. Given that in equation 1.1 I control explicitly for a rich set of other possible ways that cash crops can be correlated with the outcomes of interest, this assumption is likely to be fulfilled. Most importantly, I control for pre-colonial women's status, which could directly have an effect on women's current status in society, by controlling at the ethnicity-level for the custom of bride price, the practice of polygyny, the descent system of matriliny, and the dependence of an ethnicity on agriculture as main form of subsistence, during the pre-colonial period, using the Murdock Atlas. Table 1.4 shows that neither of these variables is significantly correlated with land suitability for cash vs. food crops.

For the two-stage least squares estimates to identify causal estimates, the instrument also needs to be a good predictor of colonial cash crop production. In Figure 1.3, I report the relationship between suitability for cash crops and its actual production. As expected, there is a significant positive relationship. The strength of the instrument is also captured by the Kleibergen-Paap F-statistic of the first stage which is reported in each regression table, and is always above 10 in the main specifications.

## 1.6 Results

In this section I present the main results of the analysis, following the identification strategy laid out in the previous section. For ease of interpretation, all outcome and main explanatory variables have been standardized.

### 1.6.1 Main Results

Table 1.5 presents the OLS and 2SLS estimates of the effect of cash crop agriculture on women's empowerment using the *Beating Free Index* in Panel A and the *Decision Index* in Panel B. Specifications include fixed effects at DHS country-round level. Column 1 reports results for a simple specification which only includes fixed effects. When looking at the *Beating Free Index* the effect of cash crop agriculture is positive and statistically significant, indicating that women with ancestors from a district with more cash crop production during colonial rule justify husbands' violence on fewer occasions. In columns 2 to 5, I add several sets of control variables, which are pre-determined with respect to colonisation to avoid potentially endogenous controls.

Column 2 adds variables that vary at the colonial-district level. These include geographic characteristics such as terrain ruggedness, general soil quality, fixed effects for vegetation type, and the presence of diamond mines. I also include population density in the 1930s and a dummy on whether Islam was the prevalent religion at the beginning of the twentieth century, which could potentially directly affect women's status as the Islamic religion in this region generally prohibited women from working outside the home. Finally, I further add the number of conflicts between 1400 and 1700 to control for levels of warfare in the pre-colonial period, since Besley and Reynal-Querol (2014) showed that a history of pre-colonial conflicts is associated with lower levels of trust today, which in turn could be associated with gender norms. Adding these controls halves the coefficient from 0.307 to 0.170, but the effect remains positive and statistically significant at the 5 percent level.

In column 3 I add ethnicity-level characteristics taken from the Murdock Atlas on women's pre-colonial status to control for women's initial level of empowerment. The coefficient on share of cash crops stays positive and significant.

Column 4 controls for ethnicity-level geographic characteristics: distance from rivers, coasts and railways, to take into account the greater likelihood of a colonial presence at or near ports. Meanwhile Jedwab and Moradi (2016) show a strong effect of rail connectivity on cash crop production, population, and urban growth. Including these variables barely changes the main results.

In column 5, instead, I add ethnicity-level information on slaves taken in the Transatlantic and Indian slave trades. I construct this variable as the logarithm of one plus the number of slaves taken from the respondent's ethnic group in the slave trade divided by the area of land historically inhabited by the group. Nunn (2008) finds a negative impact of the slave trade on long-term development, while Nunn and Wantchekon (2011) shows that current differences in trust levels within Africa, which might be associated with gender norms, can be traced back to the slaves trade. Teso (2018) directly links the Transatlantic slave trade to current women's labour force participation and gender norms. Further, Dalton and Leung (2014), Edlund and Ku (2011), and Thornton (1983) discuss the slave trade as a cause of polygamy. Adding this control shrinks the coefficient, but the positive relationship between cash crop agriculture and the *Beating Free Index* is still positive and significant at the 1 percent level.

Finally, column 6 presents results when controlling for all variables together. The coefficient of interest remains positive and statistically significant, and suggests that a one standard deviation increase in the share of land devoted to cash crops within a district leads to an increase of 0.485 of a standard deviation in the *Beating Free Index*, or 16 percentage points.

Panel B presents the same estimates using the *Decision Index* as the outcome variable. Results are significant at the 10 and 5 percent level, and they are very similar to those for the *Beating Free Index*, indicating that women from ethnicities more involved in cash crop agriculture have more decision power within the household. When looking at the preferred specification including all the controls, a coefficient size of 0.663 suggests an increase in the *Decision Index* of 23 percentage points for an increase of one standard deviation in cash crop agriculture.

The IV results are consistently larger than their OLS counterparts shown at the bottom of each column in Table 1.5. There could be a few explanations. First, as discussed above, some measurement error leading to attenuation bias is to be expected since the share of cash crop agriculture is calculated based on historical statistics and digitised maps.[19] Second, IV estimates only capture the average treatment effect for compliers, i.e. those ethnicities who produced more cash crops only because their land was more suitable for such crops with respect to others. OLS estimates can be downward biased if ethnicities that produced cash crops for reasons other than having suitable land have a persistent lower level of gender equality, a possibility discussed above. Third, the OLS estimates could be downward biased because of endogeneity if ethnicities with more regressive gender norms were also more open to cooperation with colonisers.

[19] I expect the measurement error to be classical in nature, and thus to drive OLS estimates toward zero.

### 1.6.2 Decision Index Components

A natural question when looking at the *Decision Index* is whether women's empowerment is reflected in each of its components. I group the different categories of situations in two main classes: financial decisions (final say on: large household purchases, household purchases for daily needs, spending own earnings, spending husband's earnings) and other decisions (final say on own health, and children's health care, final say on food to be cooked, and visits to family or relatives). The first two columns of Table 1.6 show that women's agency is reflected in both domains, with coefficients similar in size and significance. It is also interesting to explore whether, within the financial realm, women have decision power only with respect to their own earnings. The last two columns of the table show that while women have more agency when it comes to their earnings, they do not have decision power over the earnings of their husbands.

### 1.6.3 Effects Across Cohorts

As the DHS sample used for this analysis includes women born since the 1950s, it is also possible to check whether the long-run effect of cash crop agriculture has been dissipating over time. To analyse this, I add to the specification in equation 1.1 the treatment interacted linearly with women's year of birth. Table 1.12 in Appendix C shows the results looking at the specification with the full set of controls and finding no significant effect of the interaction term, suggesting persistence even for younger cohorts of women.

### 1.6.4 Adding Potentially Endogenous Variables: Individual Level Controls

While in Table 1.5 I only included pre-determined controls, in Table 1.7 I add current-day individual level characteristics, which could potentially be affected by colonial cash crop agriculture, and themselves affect gender equality. These include marital status, number of children, religion, urban status, and the household's geographic coordinates. Although the DHS does not provide information on individuals' incomes, it includes a categorical variable that captures wealth by ranking households into wealth quintiles from the poorest to the richest within each country. The coefficients for the *Beating Free* and the *Decision* indices of column 7 remain positive and statistically significant. Crucially, the relationship does not seem to be driven by people whose ancestors engaged in colonial cash crop production being more wealthy today, a variable often associated with greater female empowerment.

### 1.6.5 Identifying Long-Run Persistence

In this sub-section, I isolate the role played by the intergenerational transmission of cultural values from the persistent effects of the introduction of cash crop production on the external environment. I exploit the fact that many individuals of different ethnic groups have migrated over time and nowadays women of different ethnic origins live in the same location. Therefore, in columns 2 and 4 of Table 1.8, I add fixed effects for the districts where women are currently living. This specification isolates persistent cultural effects of cash crop agriculture by comparing women from different ethnic groups while keeping constant the current external environment. Both the coefficients for the two different measures of empowerment remain positive. Comparing them with the results in columns 1 and 3, the coefficient sizes halve, but statistical significance increases. Among migrants currently living in the same districts, a one standard deviation increase in ancestral districts' share of cash crop agriculture leads to an increase of almost 6 and 8 percentage points in the *Beating Free Index* and *Decision Index*, respectively.

### 1.6.6 Results for Men

Did cash crop agriculture affect only women, or did it affect men as well? Did men also gain empowerment, or change their attitudes towards women? I answer these questions using a sample of only male respondents from the same DHS surveys used in the analysis for women. The data on men were collected by DHS to provide a representative sample of men aged 15-54 at national and state levels.[20] The sample sizes of men are typically lower than those of the women, especially in the most recent surveys where the ratio of men to women interviewed is about 1 to 3. The final sample size for my regression analysis on men is 48,326 individuals.

I construct the *Beating Free Index* in the same way as before, using the questions of whether it is justified for a husband to beat his wife in different circumstances. As shown in Table 1.13 of Appendix C, men do not think it is justified to beat their wife in 85 percent of the scenarios. Regarding household agency, I construct two different indices in the spirit of the *Decision Index* for women. The first one, *Decision Index Husband-Husband* summarises the number of household decisions in which the men says he has at least some decision power. The second,

[20]While for women the targeted age is always 15-49, for males it varies. Ghana 2003, 2008 and 2014 surveys targeted age 15-59; Kenya 2003, 2008 and 2014 surveys targeted age 15-54; Malawi 2000, 2004, 2010, 2016 surveys targeted age 15-54; Nigeria 2003 and 2008 surveys targeted age 15-59, while the Nigeria 2013 survey targeted age 15-49; Uganda 2001, 2006, 2011 and 2016 surveys targeted age 15-54.

*Decision Index Husband-Wife* reflects the number of decisions in which the man thinks his wife has at least some decision power. The two indices are not symmetric, since I code the answers in a non mutually exclusive way, assigning to both the husband and the wife some degree of power when they take decisions together. As shown in Table 1.13, men say they have some decision power in four-fifths of the scenarios, while they believe women have it in 50 percent of the scenarios.

Finally, Table 1.14 in Appendix C presents the effect of colonial cash crop production on the three indices when estimating equation 1.1 on the sample of only men, using all control variables, with and without current district fixed effects. Columns 1 and 2 show the results previously obtained in the sample of women. As in the previous subsection, the results for the specification including current district fixed effects speak to the intergenerational transmission channel and highlight long-run persistence.

Column 4 of Panel A shows that in areas with higher share of colonial cash crop production, men do not justify violence towards their wives on more occasions, indicating more progressive gender norms. This is in line with the results previously found for women, as shown in column 2 of Panel A. I test the hypothesis of equality of the two coefficients, finding they are not statistically different from each other.

Columns 4 and 6 of Panel B present the results for the two *Decision* indices. While not statistically significant, the negative coefficient on column 4 reveals that, on average, men from areas with more colonial cash crop production do have less decision power, contrasting the results for women reported in column 2. These men also say that women have more decision power, as shown with the coefficient in column 6, almost statistically significant at a conventional level (p-value 0.114).

### 1.6.7 Adding Potentially Bad Controls: Christian Missions

A different strand of research which links colonialism and gender norms looks at the role played by Christian mission education on persistent gender norms. Among others, Boserup (1970), Rodney (1972), and Akyeampong and Fofack (2014) suggest that Christian mission schools provided gender-biased education, reflecting the typical Western view of the domestic role of women, while disproportionally teaching males knowledge useful for participation in the modern colonial economy. Meanwhile Jedwab et al. (2018) find that cash crop exports attracted European missionaries, making missions a potentially bad control to use.[21] In any case, taking this concern into account, Table 1.15 in Appendix C shows that adding missions as a control, with and without current district fixed effects, does not change the main results.

## 1.7 Discussion of Potential Mechanisms

In this section, I explore the mechanisms that drive the effect of cash crop agriculture on women's empowerment and its persistence over time.

### 1.7.1 Human Capital and Labour Force Participation

To shed a light on possible mechanisms, I look at two additional outcomes: education and female labour force participation. These outcomes have been long used in the literature on women's status (e.g. Acemoglu et al. (2004), Fernández (2007), Goldin and Olivetti (2013)), and are also often employed in the recent scholarship that studies the historical roots of gender roles (e.g. Becker and Woessmann (2008), Alesina et al. (2013), Nunn (2014), Teso (2018)), but they may be affected by other variables such as poverty rates or safety concerns (Duflo (2012), Borker (2017)).

Table 1.9 replicates the analyses in Table 1.7 and Table 1.8, but with years of education and labour force participation as outcome variables in Panel A and B, respectively. The coefficients on education are consistently positive and statistically significant. The effect is also quite sizeable. For instance, adding all the controls, column 8 indicates that a one standard deviation increase in a district's share of cash crop agriculture leads to an increase of one more year of education.

Panel B, on the other hand, shows no persistent effect of colonial cash crop agriculture on labour force participation, suggesting that the higher education levels are not driven by labour market opportunities or necessities. This is consistent with a mechanism that with the money from the sale of cash crops, local populations invest in household improvements and children's education (Berry (1975), Cogneau and Jedwab (2012)). Alternatively, it could also be that these women are in the lower part of the U-shaped function between labour force participation and development levels suggested in Goldin (1995) and Olivetti (2014), and for developing countries in Mammen and Paxson (2000) and Fatima and Sultana (2009).

[21] Jedwab et al. (2018) make another important contribution by collecting new data on missions in Ghana and showing that the data often used for missions in the economic history literature, Beach (1903) and Roome (1925), suffer from severe under-reporting. For instance, Beach (1903) counts 26 missions in Ghana in 1900 and Roome (1925) counts 23 in 1924, while Jedwab et al. (2018) count, respectively, 304 and 1,213. Taking this concern into account, in my analysis I use Roome (1925) data assuming these are the most important missions.

I repeat the same analysis in the sample with only male respondents. Table 1.16 in Appendix C presents the results. Panel A shows the results for education compared to the findings for women. While a higher share of colonial cash crop agriculture has a positive and statistically significant effect on women, it does not have any effect on men. A test for the equality of the two coefficients fails to reject the hypothesis that the two coefficients are the same, although the Z-statistic is 1.61 (just slightly below the conventional 1.64 for significance at the 10 percent level).

Panel B, instead, shows the results on male labour force participation. I find that men from districts with higher colonial cash crop production do work significantly more, an effect absent in the sample of women. However, the two coefficients from columns 2 and 4 are not statistically different from each other.

### 1.7.2 Crop by Crop Analysis

The analysis so far has looked at cash crop agriculture as a bundle of seven export crops: cocoa, coconut, coffee, cotton, groundnuts, palm oil and tobacco. In this section, I separate the effect of each crop and construct individual measures of production and suitability to explore whether the positive relationship between cash crop agriculture and women's status is driven particularly by some crops.

Panel A of Table 1.10 presents the crop by crop results on the two main outcomes of interest, the *Beating Free* and *Decision* indices. Each column refers to a different crop and shows the estimates of equation 1.1 with all controls and current district fixed effects. The results show that it is mainly cocoa and palm oil production that match the main results. A less clear role is played by tobacco, which has a positive effect on the *Decision Index* but a negative one on the *Beating Free Index*.[22]

In Panel B, I also look at education and labour force participation. The results reinforce the story for cocoa, which shows a positive significant coefficient for education but not for labour force participation, as in the main analysis. Palm oil production shows similar results, but differently from the main findings also the coefficient for labour force participation is significant.

What is different about cocoa and palm oil with respect to other crops? Looking at cocoa, Grier (1992), argues that in the labour-intensive processes of establishing a cocoa farm by clearing the virgin forest, planting the cocoa seeds or seedlings and intercropping with food crops, the labour of women and girls largely dominated. Austin (2014) highlights the importance of women in the establishment

[22] Also notice that the F-statistic of the first stage is above 10 only for cocoa, palm oil and tobacco.

of cocoa farms, as they planted plantain and cocoyam to shade the young cocoa plants, and reports that sometimes women were among the early cocoa farm owners.[23] This suggests that women were particularly valuable in the production of cocoa, and an expansion of production of this crop to meet demand from colonisers lead to an increasingly important role for women in the local economy, resulting in persistent, more progressive gender norms.

Also palm oil production exhibits a particularly close relationship with women's participation in cash cropping. For instance, while in Nigeria men took over the production of palm oil, previously a female activity in precolonial societies of West Africa (Maier (2009)), women were rewarded for helping in oil processing through the allocation of property rights to its by-product, the palm kernels (Martin (2006)). Thus, women living in palm fruit producing households profited directly from the production of palm oil. Byfield (2018) argues that women's involvement in palm oil processing was conspicuous at least till the post-Second World War period, to the extent that missionary accounts and colonial reports acknowledged women's important role in processing the palm fruit, while remaining silent on their involvement on other cash crops.

The crop by crop analysis also suggests that the main findings are not driven by economic growth. Even though I show in subsection 1.6.4 that including household wealth does not change the results, the effect on women's empowerment could still be partially driven by income, a variable I cannot measure since the DHS does not provide data on it. However, if this was the case, we would see significant positive results for all cash crops individually, since the production of each one leads to an increase in income, and therefore in growth.

### 1.7.3 The Marriage Market Channel

I explore whether cultural transmission within the family plays a role in explaining the long-run effect of colonial cash crop agricultural system on women's empowerment. In particular, I look at weather the persistence of values is passed on through generations by men: men of ethnicities ancestrally more involved in cash crop production could be more exposed to positive attitudes towards women, thereby granting or allowing their wives more autonomy. The role of the marriage market in the transmission of cultural values was originally formulated in Fernández et al. (2004).

If the marriage market channel is active, women with husbands ancestrally

[23] Austin (2014) draws from Kyei (2001) and specifies that where women were among the early cocoa farm owners, they tended to be "elderly and unattached", therefore freed from the obligation to help men.

more exposed to cash crop agriculture should have higher levels of empowerment, conditional on their own ethnicity. To investigate this, I follow the same approach in Teso (2018). Results are available in Table 1.17 of Appendix C.

First, to benchmark the marriage market analysis, I re-estimate equation 1.1 only on a sample of married women for whom DHS provides information on their husbands' ethnicity, as shown in columns 1 and 2, for the *Beating Free Index* and the *Decision Index*, respectively.[24] Then, in columns 3 and 4, I add country-round-wife's ethnicity fixed effect, and I use the husbands' ethnicity to link a woman from the DHS to all variables measured at the colonial-district level, and at the ethnicity level. This way, the comparison is between women whose ancestors were equally involved in cash crop production, but who married men whose ancestors' exposure varied. However, marriage decisions are likely to be endogenous since individuals tend to marry within ethnicity (in this sample, 91 percent of couples are composed by same ethnicity individuals). Thus, in columns 5 and 6, I use country-round-husband's ethnicity fixed effect to isolate the effect of a woman's ethnic group's exposure to colonial cash crop agriculture while holding fixed the ethnicity of the husband.

As shown in the table, by restricting the sample to married women for whom husbands' ethnicity is non-missing, the total observations are reduced to a fifth of the initial sample. Hence, my findings are not clear cut. Regardless of whether I include current district fixed effects or not, the results show that, on the one hand, I can not reject the hypothesis that the marriage market does not play a role in the transmission of cultural values. But, especially for the *Decision Index*, the results are noisy. Furthermore, as opposed to Teso (2018), my regressions are estimated through 2SLS, and not OLS, which may induce additional noise in this procedure, next to the already much smaller sample size.

## 1.8 Robustness

To demonstrate the robustness of my results, I construct an alternative index of cash crop suitability following Alesina et al. (2013). Instead of measuring districts' suitability for cash crop as the average suitability of the land for such products, I build an index measuring the district's share of land suitable for cash crops. Following Alesina et al.'s (2013) approach, each grid-cell is defined suitable if the yield of at least one cash crop is no less than 40 percent.

[24] Information on the ethnicity of a woman's husband is taken, when available, from the DHS "Couples' Recode" datasets.

Table 1.18 in Appendix C replicates the analysis on all outcome variables and shows IV coefficients using the new instrument. In columns 1 to 6 the results are broadly similar to the previous findings. There is a drop in significance when adding all controls together, however as in column 8, when only using variation coming from migrants the coefficients are all significant. Overall, except for the significant coefficient on labour force participation, these results are very similar to those in the main analysis on persistence, suggesting the findings are robust to different suitability measures.[25]

## 1.9 Conclusion

I show that the cash-crop production system introduced by European colonisers in the African continent had a persistent effect on women's empowerment. I exploit exogenous within-country variation in soil suitability for cash crop production for identification, and use large-scale representative surveys of the country populations.

I find that women from ethnicities with more ancestral exposure to cash crop agriculture have more agency within the household and are less willing to condone spousal violence. When looking at a sample with only male respondents, the initial results are confirmed: males from the same areas are also less likely to justify beating their wives. Further, they do not display any increase in decision power within the household, unlike women. The main results hold when looking at migrants across regions within countries, comparing women from different ethnic homelands who are now living in the same district, keeping the current environment constant. I also find no evidence of a decay in the effect of cash crop agriculture on female empowerment.

I explore possible mechanisms for these results and find that the long lasting impact of cash crop agriculture is also visible in higher education levels for women, but not in labour force participation. Further, I examine whether the effect of cash crop agriculture is driven by certain individual cash crops. I show that the results are mainly driven by cocoa and palm oil, as women played a substantial role in

[25]In the spirit of Galor and Özak (2016), I also construct two additional instruments that capture the variation in potential crop yield as measured in calories per hectare per year, reflecting the fact that land that is suitable for agriculture is not necessarily suitable for the most productive crops in terms of their caloric return. The resulting indices adapted to my scenario are one for the productivity of land as the maximum potential caloric yield per hectare, and one for the productivity advantage of cash crops versus food crops (in the original paper presented as cereals versus tubers). However, as the cash crops under consideration are very low in caloric content with respect to food crops, the resulting indices did not produce enough variation, and therefore could not predict cash crop production. Intuitively, such instruments also do not reconcile with the context of this paper, where cash crop production was a choice driven by market forces, rather than consumption ones.

producing these crops.

This work speaks to the literature on the effects of cash crop agriculture on women's status. The historical and anthropological literatures have long suggested that women's subordinate position in the cash economy had a negative impact on them. Beyond their roles in the home and in food crop production, women had to carry the extra burden of helping their husbands with cash crop agriculture, by working longer hours. On the other hand, it is not clear whether this hypothesis is consistent with contemporary economic evidence. Since cash crop agriculture often increased female labour in agriculture, as increased output was required to meet colonial taxation demands, recent literature on the determinants of gender inequality would suggest that this lead to better outcomes for women, and that these could persist into the present. My results support the second hypothesis, that women benefited from their ancestral involvement in cash crop agriculture.

These findings suggest future work in at least two directions. First, to improve external validity, it would be useful to enlarge the sample to countries colonised by other European states. While the hypothesis of the historical and anthropological literatures is not exclusive to British colonies, assembling the colonial agricultural production data for the whole continent requires significant archival effort. Second, a limitation of this analysis is the lack of colonial data on women. While the Ethnographic Atlas provides information on some aspects of pre-colonial women's status by ethnicity, no data are systematically recorded for the colonial times. Deep anthropological research on the topic would strengthen the analysis in this paper. By observing women's empowerment at three points in time: pre-colonial, colonial and post-colonial, it would be possible to draw conclusions about the trajectory of women's empowerment. For example, were the effects on women already apparent during colonial times, or only decades later, possibly due to policies countries implemented as a result of their colonial experience. These questions are left for future work.

## 1.10 Tables

**Table 1.1:** *Beating Free Index* components across DHS surveys

| | In your opinion, is a husband justified in hitting or beating his wife if she.. | | | | | |
|---|---|---|---|---|---|---|
| SURVEY | ..argues with him | ..burns food | ..goes out without telling him | ..refuses to have sex with him | ..neglects the children | ..commits infidelity |
| Ghana 2003 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Ghana 2008 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Ghana 2014 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Kenya 2003 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Kenya 2008 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Kenya 2014 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Malawi 2000 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Malawi 2004 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Malawi 2010 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Malawi 2016 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Nigeria 2003 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Nigeria 2008 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Nigeria 2013 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Uganda 2001 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Uganda 2006 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Uganda 2011 | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Uganda 2016 | ✓ | ✓ | ✓ | ✓ | ✓ | . |

Note: Ticks indicate the question is present in the specific survey.

**Table 1.2:** *Decision Index* components across DHS surveys

| | Who usually makes decision about.. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SURVEY | ..making major household purchases | ..household purchases for daily needs | ..visits to family or relatives | ..how your earning will be used | ..how husband's earnings will be used | ..health care for yourself | ..food to be cooked each day | ..health care for children |
| Ghana 2003 | ✓ | ✓ | ✓ | ✓ | . | ✓ | ✓ | . |
| Ghana 2008 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | . | . |
| Ghana 2014 | ✓ | . | ✓ | ✓ | ✓ | ✓ | . | . |
| Kenya 2003 | ✓ | ✓ | ✓ | ✓ | . | ✓ | ✓ | . |
| Kenya 2008 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Kenya 2014 | ✓ | . | ✓ | ✓ | ✓ | ✓ | ✓ | . |
| Malawi 2000 | ✓ | ✓ | ✓ | ✓ | . | ✓ | ✓ | . |
| Malawi 2004 | ✓ | ✓ | ✓ | ✓ | . | ✓ | ✓ | . |
| Malawi 2010 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | . | . |
| Malawi 2016 | ✓ | . | ✓ | ✓ | ✓ | ✓ | . | . |
| Nigeria 2003 | ✓ | ✓ | ✓ | ✓ | . | ✓ | ✓ | ✓ |
| Nigeria 2008 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | . | . |
| Nigeria 2013 | ✓ | . | ✓ | ✓ | ✓ | ✓ | . | . |
| Uganda 2001 | ✓ | ✓ | ✓ | ✓ | . | ✓ | ✓ | ✓ |
| Uganda 2006 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | . | . |
| Uganda 2011 | ✓ | . | ✓ | ✓ | ✓ | ✓ | . | . |
| Uganda 2016 | ✓ | . | ✓ | ✓ | ✓ | ✓ | . | . |

Note: Ticks indicate the question is present in the specific survey.

**Table 1.3:** Summary Statistics on Women's Empowerment

| | *N* | *Mean* | *St Dev* | *Min* | *Max* |
|---|---|---|---|---|---|
| *Beating Free Index* | 103,134 | 0.76 | 0.33 | 0 | 1 |
| Arguing | 102,516 | 0.75 | 0.43 | 0 | 1 |
| Burning food | 102,669 | 0.86 | 0.34 | 0 | 1 |
| Going out | 102,744 | 0.73 | 0.44 | 0 | 1 |
| Refusing sex | 101,896 | 0.79 | 0.40 | 0 | 1 |
| Neglecting kids | 102,699 | 0.68 | 0.46 | 0 | 1 |
| Committing infidelity | 4,771 | 0.49 | 0.50 | 0 | 1 |
| | | | | | |
| *Decision Index* | 103,134 | 0.58 | 0.36 | 0 | 1 |
| Big purchases | 102,704 | 0.49 | 0.49 | 0 | 1 |
| Daily purchases | 54,359 | 0.52 | 0.49 | 0 | 1 |
| Visiting family | 102,771 | 0.65 | 0.47 | 0 | 1 |
| Own earnings | 54,356 | 0.85 | 0.35 | 0 | 1 |
| Husband's earnings | 74,772 | 0.43 | 0.49 | 0 | 1 |
| Own healthcare | 102,970 | 0.57 | 0.49 | 0 | 1 |
| Deciding food | 38,676 | 0.71 | 0.45 | 0 | 1 |
| Kids healthcare | 3,625 | 0.37 | 0.48 | 0 | 1 |
| | | | | | |
| *Education* | 103,134 | 6.21 | 4.59 | 0 | 26 |
| | | | | | |
| *Labour Force Participation* | 103,134 | 0.74 | 0.44 | 0 | 1 |
| Agricultural | 33,121 (43.29%) | | | | |
| Clerical | 21,259 (27.78%) | | | | |
| Household, Services | 6,721 (8.78%) | | | | |
| Manual worker | 7,281 (9.52%) | | | | |
| Professional, Managerial | 6,328 (8.27%) | | | | |
| Other | 54 (0.07%) | | | | |
| Missing information | 1,749 (2.29%) | | | | |

Note: Unit of observation is a DHS respondent. *Beating Free Index* and *Decision Index* are constructed as explained in main text. Education is measured in years of education. Labour Force Participation is a dummy equal to 1 if a woman was employed in the 12 months before the survey.

**Table 1.4:** Instrument and Pre-colonial Measures of Women's Status

| | (1) Bride price | (2) Polygyny | (3) Matriliny | (4) Dependence on Agriculture |
|---|---|---|---|---|
| Cash Crop Suitability Index | 0.031 | 0.008 | 0.029 | -0.032 |
| | (0.023) | (0.007) | (0.051) | (0.036) |
| Observations | 91 | 91 | 91 | 91 |

Notes: Table reports OLS estimates. Unit of observation is as ethnicity. Cash Crop Suitability Index is the instrument as constructed in equation 1.2. Bride price is a dummy equal to 1 if bride price is customary; Polygyny is a dummy equal to 1 if polygyny is practised instead of monogamy; Matriliny is a dummy equal to 1 if the system of descent is not patrilineal; Dependence on agriculture is a percentage of an ethnicity dependence on such activity as main source of subsistence. Standard errors clustered at the district level. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 1.5:** Women's Empowerment and Colonial Cash Crops

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Panel A: *Beating Free Index* | | | | | |
| 2SLS Share Cash Crop | 0.307*** | 0.170** | 0.225*** | 0.211*** | 0.143*** | 0.485** |
| | (0.115) | (0.078) | (0.085) | (0.060) | (0.040) | (0.233) |
| OLS Share Cash Crop | 0.053* | 0.034 | 0.037 | 0.023 | 0.046** | 0.059 |
| | (0.028) | (0.029) | (0.027) | (0.031) | (0.023) | (0.046) |
| | Panel B: *Decision Index* | | | | | |
| 2SLS Share Cash Crop | 0.342* | 0.215** | 0.202** | 0.137** | 0.151** | 0.663* |
| | (0.178) | (0.092) | (0.103) | (0.067) | (0.066) | (0.351) |
| OLS Share Cash Crop | -0.022 | -0.022 | -0.040 | -0.065** | -0.030 | -0.051 |
| | (0.033) | (0.025) | (0.025) | (0.032) | (0.026) | (0.041) |
| FE Country-round | Y | Y | Y | Y | Y | Y |
| Colonial District Controls | | Y | | | | Y |
| Pre Col. Ethnicity Controls | | | Y | | | Y |
| Distance Controls | | | | Y | | Y |
| Slave Trade Controls | | | | | Y | Y |
| K-P F-stat | 13.09 | 13.69 | 13.57 | 15.73 | 24.97 | 8.917 |
| Clusters | 91 | 91 | 91 | 91 | 91 | 91 |
| Observations | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 |

Notes: Table reports OLS and 2SLS estimates. Unit of observation is a DHS respondent. *Beating Free Index* and *Decision Index* are constructed as explained in main text. Share Cash Crop is the percentage of a district area dedicated to cash crops. Colonial District Controls: dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices; Pre Colonial Ethnicity Controls: dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid; Distance Controls: ethnicity's homeland distance from closest railroad, coast and rivers; Slave Trade Controls: log of 1 + number of Transatlantic and Indian slaves by ethnicity's area. Standard errors clustered at the ethnicity level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 1.6:** *Decision Index* Components

| | (1) Other Decisions | (2) Financial Decisions | (3) Own Earnings | (4) Husband's Earnings |
|---|---|---|---|---|
| Share Cash Crop | 0.696** | 0.522** | 0.185*** | 0.169 |
| | (0.349) | (0.253) | (0.069) | (0.104) |
| FE Country-round | Y | Y | Y | Y |
| Colonial District Controls | Y | Y | Y | Y |
| Pre Col. Ethnicity Controls | Y | Y | Y | Y |
| Distance Controls | Y | Y | Y | Y |
| Slave Trade Controls | Y | Y | Y | Y |
| K-P F-stat | 9.067 | 9.067 | 9.067 | 9.067 |
| Clusters | 89 | 89 | 89 | 89 |
| Observations | 42,413 | 42,413 | 42,413 | 42,413 |

Notes: Table reports 2SLS estimates. Unit of observation is a DHS respondent. Outcome variables are indices on Financial Decisions (making large household purchases, household purchases for daily needs, spending women own earnings, spending husband's earnings), Other Decisions (visits to family or relatives, food to be cooked, women own health care, and children's health care), Own Earnings management and Husband's Earning management. Share Cash Crop is the percentage of a district area dedicated to cash crops. Colonial District Controls: dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices; Pre Colonial Ethnicity Controls: dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid; Distance Controls: ethnicity's homeland distance from closest railroad, coast and rivers; Slave Trade Controls: log of 1 + number of Transatlantic and Indian slaves by ethnicity's area. Standard errors clustered at the ethnicity level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively. The total number of observations is different with respect to the main analysis. This is because I sample women who have been asked and answered at least one question within each of the two categories, "Financial Decisions" and "Other Decisions", for the split in column 1 and 2, and women who have been asked and answered both questions on Own and Husband's Earnings for the split in column 3 and 4. Results are robust to different splits of the sample.

**Table 1.7:** Adding Potentially Endogenous Variables

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | | | | Panel A: *Beating Free Index* | | | |
| 2SLS Share Cash Crop | 0.307*** | 0.078** | 0.170** | 0.225*** | 0.211*** | 0.143*** | 0.314** |
| | (0.115) | (0.033) | (0.078) | (0.095) | (0.060) | (0.040) | (0.152) |
| OLS Share Cash Crop | 0.053* | 0.009 | 0.034 | 0.037 | 0.023 | 0.046** | 0.036 |
| | (0.028) | (0.012) | (0.029) | (0.027) | (0.031) | (0.023) | (0.038) |
| | | | | Panel B: *Decision Index* | | | |
| 2SLS Share Cash Crop | 0.342* | 0.099** | 0.215** | 0.202** | 0.137** | 0.151** | 0.511** |
| | (0.178) | (0.047) | (0.092) | (0.103) | (0.067) | (0.066) | (0.258) |
| OLS Share Cash Crop | -0.022 | -0.058*** | -0.022 | -0.040 | -0.065** | -0.030 | -0.049 |
| | (0.033) | (0.020) | (0.025) | (0.025) | (0.032) | (0.026) | (0.035) |
| FE Country-round | Y | Y | Y | Y | Y | Y | Y |
| Individual Controls | | Y | | | | | Y |
| Colonial District Controls | | | Y | | | | Y |
| Pre Col. Ethnicity Controls | | | | Y | | | Y |
| Distance Controls | | | | | Y | | Y |
| Slave Trade Controls | | | | | | Y | Y |
| K-P F-stat | 13.09 | 20.55 | 13.69 | 13.57 | 15.73 | 24.97 | 10.34 |
| Clusters | 91 | 91 | 91 | 91 | 91 | 91 | 91 |
| Observations | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 |

Notes: Table reports OLS and 2SLS estimates. Unit of observation is a DHS respondent. *Beating Free Index* and *Decision Index* are constructed as explained in main text. Share Cash Crop is the percentage of a district area dedicated to cash crops. Individual Controls: age, dummy for religion, dummy for marital status, number of children, dummy for urban vs. rural status, dummy for household wealth's quantile, household's geographic coordinates; Colonial District Controls: dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices; Pre Colonial Ethnicity Controls: dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid; Distance Controls: ethnicity's homeland distance from closest railroad, coast and rivers; Slave Trade Controls: log of 1 + number of Transatlantic and Indian slaves by ethnicity's area. Standard errors clustered at the ethnicity level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 1.8:** Intergenerational Transmission of Women's Empowerment

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | *Beating Free Index* | | *Decision Index* | |
| 2SLS Share Cash Crop | 0.314** | 0.169** | 0.511** | 0.232*** |
| | (0.152) | (0.071) | (0.258) | (0.069) |
| OLS Share Cash Crop | 0.036 | 0.001 | -0.049 | 0.021 |
| | (0.038) | (0.031) | (0.035) | (0.023) |
| FE Country-round | Y | Y | Y | Y |
| FE Current Districts | | Y | | Y |
| Individual Controls | Y | Y | Y | Y |
| Colonial District Controls | Y | Y | Y | Y |
| Pre Col. Ethnicity Controls | Y | Y | Y | Y |
| Distance Controls | Y | Y | Y | Y |
| Slave Trade Controls | Y | Y | Y | Y |
| K-P F-stat | 10.34 | 26.86 | 10.34 | 26.86 |
| Clusters | 91 | 91 | 91 | 91 |
| Observations | 103,134 | 103,134 | 103,134 | 103,134 |

Notes: Table reports OLS and 2SLS estimates. Unit of observation is a DHS respondent. *Beating Free Index* and *Decision Index* are constructed as explained in main text. Share Cash Crop is the percentage of a district area dedicated to cash crops. Individual Controls: age, dummy for religion, dummy for marital status, number of children, dummy for urban vs. rural status, dummy for household wealth's quantile, household's geographic coordinates; Colonial District Controls: dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices; Pre Colonial Ethnicity Controls: dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid; Distance Controls: ethnicity's homeland distance from closest railroad, coast and rivers; Slave Trade Controls: log of 1 + number of Transatlantic and Indian slaves by ethnicity's area. Standard errors clustered at the ethnicity level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 1.9:** Women's Human Capital and Labour Force Participation

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | | | | Panel A: Education | | | | |
| 2SLS Share Cash Crop | 0.711** | 0.223*** | 0.334*** | 0.462*** | 0.467*** | 0.375*** | 0.335* | 0.222** |
| | (0.302) | (0.079) | (0.106) | (0.168) | (0.168) | (0.114) | (0.180) | (0.088) |
| OLS Share Cash Crop | 0.124** | 0.037* | 0.098** | 0.092* | 0.049 | 0.109*** | 0.029 | 0.012 |
| | (0.052) | (0.021) | (0.043) | (0.047) | (0.055) | (0.038) | (0.043) | (0.039) |
| | | | | Panel B: Labour Force Participation | | | | |
| 2SLS Share Cash Crop | 0.051 | -0.020 | 0.005 | -0.004 | -0.026 | -0.006 | 0.066 | 0.036 |
| | (0.052) | (0.018) | (0.017) | (0.022) | (0.017) | (0.022) | (0.048) | (0.032) |
| OLS Share Cash Crop | -0.019** | -0.025*** | -0.015** | -0.013* | -0.037*** | -0.022** | 0.025* | 0.010 |
| | (0.008) | (0.008) | (0.008) | (0.007) | (0.010) | (0.009) | (0.013) | (0.012) |
| FE Country-round | Y | Y | Y | Y | Y | Y | Y | Y |
| FE Current Districts | | | | | | | | Y |
| Individual Controls | | Y | | | | | Y | Y |
| Colonial District Controls | | | Y | | | | Y | Y |
| Pre Col. Ethnicity Controls | | | | Y | | | Y | Y |
| Distance Controls | | | | | Y | | Y | Y |
| Slave Trade Controls | | | | | | Y | Y | Y |
| K-P F-stat | 13.09 | 20.55 | 13.69 | 13.57 | 15.73 | 24.97 | 10.34 | 26.86 |
| Clusters | 91 | 91 | 91 | 91 | 91 | 91 | 91 | 91 |
| Observations | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 |

Notes: Table reports OLS and 2SLS estimates. Unit of observation is a DHS respondent. Education is measured in years of education. Labour Force Participation is a dummy equal to 1 if a woman was employed in the last 12 months before the survey. Share Cash Crop is the percentage of a district area dedicated to cash crops. Individual Controls: age, dummy for religion, dummy for marital status, number of children, dummy for urban vs. rural status, dummy for household wealth's quantile, household's geographic coordinates; Colonial District Controls: dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices; Pre Colonial Ethnicity Controls: dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid; Distance Controls: ethnicity's homeland distance from closest railroad, coast and rivers; Slave Trade Controls: log of 1 + number of Transatlantic and Indian slaves by ethnicity's area. Standard errors clustered at the ethnicity level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

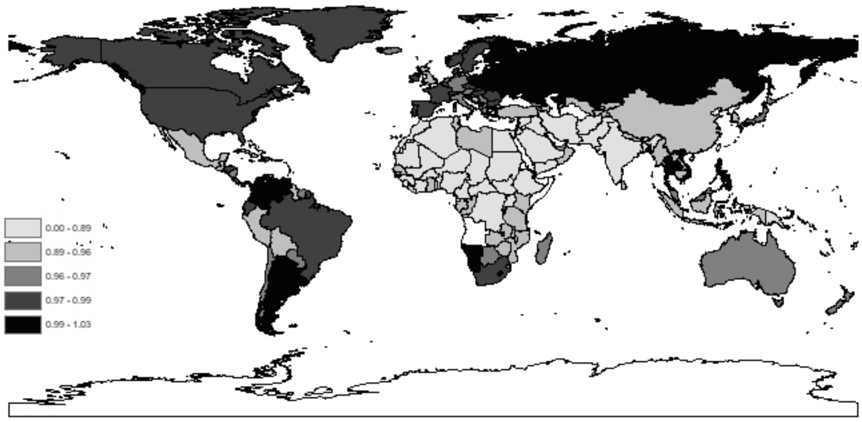
**Table 1.10:** Crop by Crop Analysis

| *Dependent Variable* | (1) Cocoa | (2) Coffee | (3) Copra | (4) Cotton | (5) Groundnuts | (6) Palm Oil | (7) Tobacco |
|---|---|---|---|---|---|---|---|
| | | | | Panel A | | | |
| *Beating Free Index* | 0.145** | -0.193 | 0.030 | 0.012 | 0.155 | 0.276** | -0.022 |
| | (0.066) | (0.196) | (0.049) | (0.159) | (0.361) | (0.119) | (0.038) |
| *Decision Index* | 0.243*** | -0.576** | 0.132* | 0.182 | 0.201 | 0.269** | 0.111*** |
| | (0.046) | (0.225) | (0.070) | (0.185) | (0.377) | (0.119) | (0.037) |
| | | | | Panel B | | | |
| *Education* | 0.206** | -0.395 | 0.054 | -0.393 | 0.119 | 0.269* | -0.061 |
| | (0.094) | (0.420) | (0.063) | (0.400) | (0.533) | (0.162) | (0.059) |
| *Labour Force Participation* | -0.023 | -0.406* | 0.024 | -0.381* | 0.449 | 0.094** | -0.050** |
| | (0.031) | (0.210) | (0.028) | (0.199) | (0.828) | (0.046) | (0.020) |
| FE Country-round | Y | Y | Y | Y | Y | Y | Y |
| FE Current Districts | Y | Y | Y | Y | Y | Y | Y |
| Individual Controls | Y | Y | Y | Y | Y | Y | Y |
| Colonial District Controls | Y | Y | Y | Y | Y | Y | Y |
| Pre Col. Ethnicity Controls | Y | Y | Y | Y | Y | Y | Y |
| Distance Controls | Y | Y | Y | Y | Y | Y | Y |
| Slave Trade Controls | Y | Y | Y | Y | Y | Y | Y |
| K-P F-stat | 73.66 | 9.956 | 3.504 | 4.196 | 0.336 | 16.43 | 25.19 |
| Clusters | 91 | 91 | 91 | 91 | 91 | 91 | 91 |
| Observations | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 |

Notes: Table reports 2SLS estimates. Unit of observation is a DHS respondent. Outcome variables are constructed as explained in main text. Individual Controls: age, dummy for religion, dummy for marital status, number of children, dummy for urban vs. rural status, dummy for household wealth's quantile, household's geographic coordinates; Colonial District Controls: dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices; Pre Colonial Ethnicity Controls: dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid; Distance Controls: ethnicity's homeland distance from closest railroad, coast and rivers; Slave Trade Controls: log of 1 + number of Transatlantic and Indian slaves by ethnicity's area. Standard errors clustered at the ethnicity level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

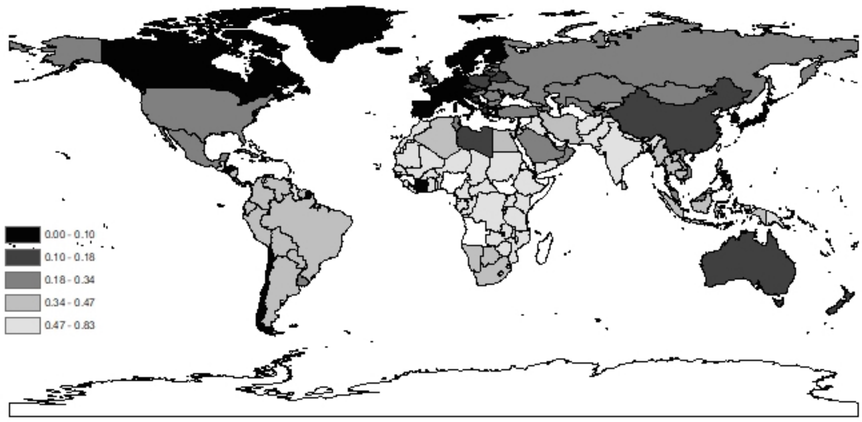
## 1.11 Figures

**Figure 1.1:** Gender Development Index, 2017



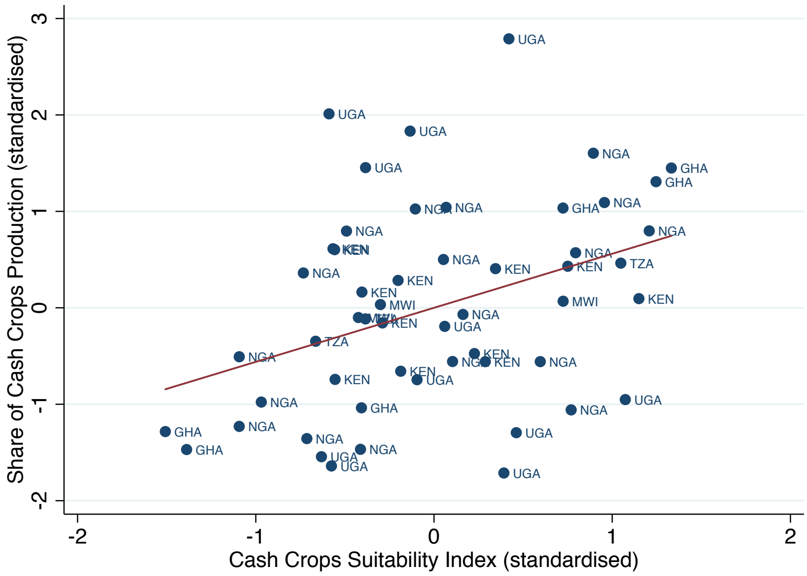

Notes: World distribution of Gender Development Index in 2017, in quintiles. It takes lower values when gender disparities are greater, therefore darker areas indicates higher levels of women's empowerment. Source: http://www.undp.org. Data accessed on April 2019.

**Figure 1.2:** Gender Inequality Index, 2017




Notes: World distribution of Gender Inequality Index in 2017, in quintiles. It takes higher values when gender inequalities are bigger, therefore darker areas indicates higher levels of women's empowerment. Source: http://www.undp.org. Data accessed on April 2019.

**Figure 1.3:** Cash Crops Suitability and Cash Crops Production




Notes: The unit of observation is a colonial district. The figure represents the relationship between the share of districts' area dedicated to cash crop production (standardised) and the suitability of such districts for cash crops against overall suitability (standardised), as computed in equation 1.2. ISO codes used for countries: GHA (Ghana), KEN (Kenya), MWI (Malawi), NGA (Nigeria), TZA (Tanzania), UGA (Ugnada).

## 1.12 Appendix A: List of Variables Used in the Paper

**Outcome Variables for Women**

*Beating Free Index*: share of questions on attitudes towards domestic violence for which a woman answers that it is justified for a husband to beat his wife. Index components: if she argues with the partner, if she burns food, if she goes out without telling the partner, if she refuses to have sex, if she neglects the children, if she commits infidelity. Since the answer to some of these questions can be missing for some respondents, this variable should be intended as the share of instances for which the respondent answers that beating is justified among the questions with non-missing information. Individuals answering while the husband is present have been excluded. Source DHS (Individual Recode).

*Decision Index*: share of questions on a woman's participation in household decisions for which the woman answers that she has a say in the decision, even when the decision is taken together with her partner. Questions include decisions regarding: major household purchases, household purchases for daily needs, visits to family or relatives, how her earnings are used, how partner's earnings are used, her own health care, children's healthcare, food to be cooked each day. Since the answer to some of these questions can be missing for some respondents, this variable should be intended as the share of decisions for which the woman has a say among the decisions with non-missing information. Source DHS (Individual Recode).

*Education*: years of education. Source DHS (Individual Recode).

*Labour Force Participation*: dummy taking value one if respondent was employed in the last 12 months before survey. Source DHS (Individual Recode).

**Outcome Variables for Men**

*Beating Free Index*: share of questions on attitudes towards domestic violence for which a man answers that it is justified for a husband to beat his wife. Index components: if she argues with the partner, if she burns food, if she goes out without telling the partner, if she refuses to have sex, if she neglects the children, if she commits infidelity. Since the answer to some of these questions can be missing for some respondents, this variable should be intended as the share of instances for which the respondent answers that beating is justified among the questions with non-missing information. Source DHS (Men's Recode).

*Decision Index Husband-Husband*: share of questions on a men's participation in household decisions for which the man answers that he has a say in the decision, even when the decision is taken together with his partner. Questions include deci-

sions regarding: major household purchases, household purchases for daily needs, visits to family or relatives, how his earnings are used, how partner's earnings are used, his own health care, food to be cooked each day. Since the answer to some of these questions can be missing for some respondents, this variable should be intended as the share of decisions for which the man has a say among the decisions with non-missing information. Source DHS (Men's Recode).
*Decision Index Husband-Wife*: share of questions on a woman's participation in household decisions for which the man answers that she has a say in the decision, even when the decision is taken together with his partner. Questions include decisions regarding: major household purchases, household purchases for daily needs, visits to family or relatives, how his earnings are used, how partner's earnings are used, his own health care, food to be cooked each day. Since the answer to some of these questions can be missing for some respondents, this variable should be intended as the share of decisions for which the man has a say among the decisions with non-missing information. Source DHS (Men's Recode).
*Education*: years of education. Source DHS (Men's Recode).
*Labour Force Participation*: dummy taking value one if respondent was employed in the last 12 months before survey. Source DHS (Men's Recode).

**Main Explanatory Variable**
*Share Cash Crop*: share of a colonial district's area dedicated to the production of cash crops (cocoa, coffee, copra, cotton, groundnuts, palm oil and tobacco). Source for cash crops' production area at colonial district level and total district areas: sources in Appendix B.

**Instrumental Variables**
*Suitability for Cash Crop*: average suitability of a district for cash crops (cocoa, coffee, copra, cotton, groundnuts, palm oil and tobacco) divided by average suitability of a district for cash crops and food crops (banana, cassava, foxtail and pearl millet, maize, phaseolu beans, dry and wet rice, sorghum, sweet and white potato, sugar beet, sugar cane, wheat). Source: FAO-GAEZ.
*Area Suitable for Cash Crop*: district area suitable for cash crops (cocoa, coffee, copra, cotton, groundnuts, palm oil and tobacco) over district area. Each grid-cell is defined suitable if the yield of at least one cash crop is no less than 40 percent. This approach follows Alesina et al. (2013). Source: FAO-GAEZ.
*Caloric Indices*: 1) productivity of land as the maximum potential caloric yield per hectare, 2) productivity advantage of cash crops versus food crops. This approach

follows Galor and Özak (2016). Source: Galor and Özak (2016).

**Individual Level Controls**

*Age*: age of the respondent. Source: DHS (Individual Recode).

*Urban*: dummy taking value one if respondent lives in a urban location. Source: DHS (Individual Recode).

*Married*: dummy taking value one if respondent is married. Source: DHS (Individual Recode).

*Religion*: dummies for different religions. Source: DHS (Individual Recode).

*Number of children*: number of children ever born. Source: DHS (Individual Recode).

*Wealth*: dummies for household-level wealth quintiles. Source DHS (Individual Recode).

*Latitude*: latitude of respondent's DHS cluster. Source DHS (Geographic Data).

*Longitude*: longitude of respondent's DHS cluster. Source DHS (Geographic Data).

**Colonial Districts Level Historical Controls**

*Islam*: dummy taking value 1 if main religion is Islam. Source: Bartholomew and Brooke (1918).

*Population Density in 1930.* Source Historical Database of the Global Environment.

*Colonial district area*: area of colonial district in squared kilometres. Computed in ArcGIS.

*Vegetation type*: dummies for dominant vegetation type. Source White (1983).

*Ruggedness*: average of soil ruggedness weighting grid-cells by their sea-level surface area. Source: Nunn and Puga (2012).

*Nutrient availability*: indexed composed by soil texture, soil organic carbon, soil pH, total exchangeable bases, all averaged at district level. Source: FAO.

*Land workability*: indexed composed by soil texture, effective soil depth/volume, and soil phases constraining soil management, all averaged at district level. Source: FAO.

*General land suitability index*: suitability of land for cultivation based on climate and soil constraints, averaged at district level. Source: Ramankutty et al. (2002).

*Diamond mines*: number of diamond mines divided by the district area. Source: Lujala et al. (2005)'s DIADATA.

*Precolonial conflicts*: number of conflicts between 1400 and 1700 in the district area. Source Brecke (1999).

*Christian missions*: number of Christian missions in the district area. Source Roome

(1925).

**Distance Controls**

*Distance from rivers*: the distance of the centroid of the land historically inhabited by the ethnic group from the closest river. Source for rivers: Natural Earth Data; source for ancestral land: Murdock (1959).

*Distance from coast*: the distance of the centroid of the land historically inhabited by the ethnic group from the closest coast. Source for coast: Natural Earth Data; source for ancestral land: Murdock (1959).

*Distance from railway*: the distance of the centroid of the land historically inhabited by the ethnic group from the closest railway line built before 1960. Source for railway: Jedwab and Moradi (2016); source for ancestral land: Murdock (1959).

**Ethnicity's Homeland Level Controls**

*ln(1+Slave trade/area)*: logarithm of 1 plus the number of slaves taken from the respondent's ethnic group in the Transatlantic and Indian slave trade divided by the area of land historically inhabited by the group. Source: Nunn and Wantchekon (2011); source for ancestral land: Murdock (1959).

**Pre-Colonial Ethnicity Level Controls**

*Bride price*: comes from variable v6 of the Ethnographic Atlas; I create a dummy variable for bride price taking value 1 if the prevalent mode of marriage prior to industrialization was characterized by bride price or wealth to bride's family, bride service to bride's family or token bride price, and taking value 0 in the remaining cases of absence of consideration, dowry, reciprocal gift exchange, or sister or female relative exchanged for bride. Source: Murdock (1967).

*Polygyny*: comes from variable v9 of the Ethnographic Atlas; I create a dummy for polygyny taking value 1 if the prevalent marital composition was independent nuclear (polygyny), non-sororal (cowives in same dwellings), non-sororal (cowives in separate dwellings), preferentially sororal (cowives in separate dwellings), independent polyandrous families, and taking value 0 in the remaining case of independent nuclear (monogamous). Source: Murdock (1967).

*Matriliny*: comes from variable v43 of the Ethnographic Atlas; I create a dummy for matriliny taking value 1 if the prevalent descent system was not solely based on the patrilineal line, therefore: matrilineal, duolateral, bilateral, ambilineal, mixed, and taking value 0 in the remaining case of patrilineal. Source: Murdock (1967).

*Subsistence Economy Agriculture*: comes from variable v42 of the Ethnographic

Atlas, which reports which activity (agriculture, fishing, gathering, hunting, pastoralism) is mainly practised for subsistence. I create a dummy taking value 1 if what contributes most to the economy is extensive agriculture, intensive agriculture, or agriculture type unknown, and taking value 0 otherwise. Source: Murdock (1967).

*Ethnicity latitude*: latitude of the centroid of the land historically inhabited by the ethnic group. Source: Murdock (1967).

*Ethnicity longitude*: longitude of the centroid of the land historically inhabited by the ethnic group. Source: Murdock (1967).

*Year of observation*: year in which an ethnicity has been observed for the construction of the variables in Murdock's Atlas (1967). Source: Murdock (1967).

## 1.13 Appendix B: Colonial Agricultural Production Sources

**Gold Coast**

District borders are the administrative borders from 1930 as reported in the "Administration Report 1930" (National Archives CO98/55,58). District-level production data are estimated using maps in Cardinall (1932) and Kaplan (1971).

**Kenya**

District borders are the administrative borders from 1931 as reported in the "Administration Report 1931" (National Archives CO544/33,34). District-level production data are obtained from Kenya "Agricultural Census 1930".

**Nigeria**

District level data for Nigeria is not available. Instead, I use provinces. Province borders are retrieved from Papaioannou (2016). District-level production data are estimated using maps from Austin (2009), Berry (1975), Hopkins (1973), and Iloeje & FAO (2001).

**Nyasaland**

District borders are the administrative borders from 1928 as reported in the "Administration Report 1933" (National Archives CO626/12). District-level production data are obtained from the Nyasaland Blue Books (1923, 1925, 1927, 1929, 1931, 1933, 1935, 1937, 1939).

**Tanganyika**

District borders are the administrative borders from 1933 reported in Berry (1971). District-level production data are obtained from the Tanganyika Blue Books (1926, 1927, 1929, 1930, 1932, 1933, 1935, 1937, 1938, and 1939).

**Uganda**

District borders are the administrative borders from 1950 as reported in the "Administration Report 1948" (National Archives CO685/31). District-level production data are obtained from the Uganda Blue Books (1920, 1923, 1926, 1929, 1932, 1935, 1938).

## 1.14 Appendix C: Additional Tables

**Table 1.11:** Robustness to Different Standard Errors (Main Results)

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | | | | Panel A: *Beating Free Index* | | | | |
| 2SLS Share Cash Crop | 0.307 | 0.078 | 0.170 | 0.225 | 0.211 | 0.143 | 0.314 | 0.169 |
| | (0.115) | (0.033) | (0.078) | (0.085) | (0.060) | (0.040) | (0.152) | (0.071) |
| | [0.119] | [0.033] | [0.081] | [0.100] | [0.062] | [0.042] | [0.144] | [0.067] |
| OLS Share Cash Crop | 0.053 | 0.009 | 0.034 | 0.037 | 0.023 | 0.046 | 0.036 | 0.001 |
| | (0.028) | (0.012) | (0.029) | (0.027) | (0.031) | (0.023) | (0.038) | (0.031) |
| | [0.028] | [0.012] | [0.029] | [0.027] | [0.031] | [0.023] | [0.038] | [0.031] |
| | | | | Panel B: *Decision Index* | | | | |
| 2SLS Share Cash Crop | 0.342 | 0.099 | 0.215 | 0.202 | 0.137 | 0.151 | 0.511 | 0.232 |
| | (0.18) | (0.05) | (0.09) | (0.10) | (0.07) | (0.07) | (0.26) | (0.07) |
| | [0.187] | [0.055] | [0.096] | [0.120] | [0.073] | [0.072] | [0.276] | [0.069] |
| OLS Share Cash Crop | -0.022 | -0.058 | -0.022 | -0.040 | -0.065 | -0.030 | -0.049 | 0.021 |
| | (0.033) | (0.020) | (0.025) | (0.025) | (0.032) | (0.026) | (0.035) | (0.023) |
| | [0.033] | [0.020] | [0.025] | [0.025] | [0.032] | [0.026] | [0.035] | [0.023] |
| | | | | Panel C: Eduction | | | | |
| 2SLS Share Cash Crop | 0.711 | 0.223 | 0.334 | 0.462 | 0.467 | 0.375 | 0.335 | 0.222 |
| | (0.302) | (0.079) | (0.106) | (0.168) | (0.168) | (0.114) | (0.180) | (0.088) |
| | [0.319] | [0.087] | [0.117] | [0.197] | [0.182] | [0.124] | [0.191] | [0.086] |
| OLS Share Cash Crop | 0.124 | 0.037 | 0.098 | 0.092 | 0.049 | 0.109 | 0.029 | 0.012 |
| | (0.052) | (0.021) | (0.043) | (0.047) | (0.055) | (0.038) | (0.043) | (0.039) |
| | [0.052] | [0.021] | [0.043] | [0.047] | [0.055] | [0.038] | [0.043] | [0.039] |
| | | | | Panel D: Labour Force Participation | | | | |
| 2SLS Share Cash Crop | 0.051 | -0.020 | 0.005 | -0.004 | -0.026 | -0.006 | 0.066 | 0.036 |
| | (0.052) | (0.018) | (0.017) | (0.022) | (0.017) | (0.022) | (0.048) | (0.032) |
| | [0.055] | [0.021] | [0.018] | [0.023] | [0.019] | [0.026] | [0.046] | [0.033] |
| OLS Share Cash Crop | -0.019 | -0.025 | -0.015 | -0.013 | -0.037 | -0.022 | 0.025 | 0.010 |
| | (0.008) | (0.008) | (0.007) | (0.008) | (0.010) | (0.009) | (0.013) | (0.012) |
| | [0.008] | [0.008] | [0.007] | [0.008] | [0.010] | [0.009] | [0.013] | [0.012] |
| FE Country-round | Y | Y | Y | Y | Y | Y | Y | Y |
| FE Current Districts | | | | | | | | Y |
| Individual Controls | | Y | | | | | Y | Y |
| Colonial District Controls | | | Y | | | | Y | Y |
| Pre Col. Ethnicity Controls | | | | Y | | | Y | Y |
| Distance Controls | | | | | Y | | Y | Y |
| Slave Trade Controls | | | | | | Y | Y | Y |
| Observations | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 |

Notes: Table reports OLS and 2SLS estimates. Standard errors in ( ) are clustered at the ethnicity level; Standard errors in [ ] are two-way clustered at ethnicity and country of origin level. Unit of observation is a DHS respondent. *Beating Free Index* and *Decision Index* are constructed as explained in main text. Education is measured in years of education. Labour force Participation is a dummy equal to 1 if a men was employed in the last 12 months before the survey. Share Cash Crop is the percentage of a district area dedicated to cash crops. Individual Controls: age, dummy for religion, dummy for marital status, number of children, dummy for urban vs. rural status, dummy for household wealth's quantile, household's geographic coordinates; Colonial District Controls: dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices; Pre Colonial Ethnicity Controls: dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid; Distance Controls: ethnicity's homeland distance from closest railroad, coast and rivers; Slave Trade Controls: log of 1 + number of Transatlantic and Indian slaves by ethnicity's area.

**Table 1.12:** Dissipation Over Time

| | (1) *Beating Free Index* | (2) *Decision Index* |
|---|---|---|
| Share Cash Crop | 0.467** | 0.587* |
| | (0.229) | (0.319) |
| Share Cash Crop × Birth Year | -0.024 | -0.065 |
| | (0.026) | (0.043) |
| FE Country-round | Y | Y |
| Colonial District Controls | Y | Y |
| Pre Col. Ethnicity Controls | Y | Y |
| Distance Controls | Y | Y |
| Slave Trade Controls | Y | Y |
| Clusters | 91 | 91 |
| Observations | 103,134 | 103,134 |

Notes: Table reports 2SLS estimates. Unit of observation is a DHS respondent. *Beating Free Index* and *Decision Index* are constructed as explained in main text. Share Cash Crop is the percentage of a district area dedicated to cash crops. Birth Year is standardised to the original DHS variable's mean and standard deviation. Colonial District Controls: dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices; Pre Colonial Ethnicity Controls: dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid; Distance Controls: ethnicity's homeland distance from closest railroad, coast and rivers; Slave Trade Controls: log of 1 + number of Transatlantic and Indian slaves by ethnicity's area. Standard errors clustered at the ethnicity level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 1.13:** Summary Statistics on Men's Sample

| | *N* | *Mean* | *St Dev* | *Min* | *Max* |
|---|---|---|---|---|---|
| *Beating Free Index* | 48,326 | 0.85 | 0.26 | 0 | 1 |
| *Decision Index Husband-Husband* | 48,326 | 0.81 | 0.26 | 0 | 1 |
| *Decision Index Husband-Wife* | 48,326 | 0.50 | 0.37 | 0 | 1 |
| Education | 48,326 | 7.97 | 4.54 | 0 | 25 |
| Labour Force Participation | 48,326 | 0.87 | 0.34 | 0 | 1 |

Note: Unit of observation is a DHS respondent. *Beating Free Index* and *Decision Indices* are constructed as explained in main text. Education is measured in years of education. Labour Force Participation is a dummy equal to 1 if a man was employed in the 12 months before the survey.

**Table 1.14:** Gender Norms and Men's Empowerment

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Panel A: *Beating Free Index* | | | | | |
| | Women Sample | | Men Sample | | | |
| Share Cash Crop | 0.314** | 0.169** | 0.064 | 0.126* | | |
| | (0.152) | (0.071) | (0.089) | (0.071) | | |
| | Panel B: *Decision Indices* | | | | | |
| | | | *Husband-Husband* | | *Husband-Wife* | |
| | Women Sample | | Men Sample | | Men Sample | |
| Share Cash Crop | 0.511** | 0.232*** | 0.033 | -0.069 | 0.326 | 0.102 |
| | (0.258) | (0.069) | (0.076) | (0.051) | (0.130) | (0.064) |
| FE Country-round | Y | Y | Y | Y | Y | Y |
| FE Current Districts | | Y | | Y | | Y |
| All Controls | Y | Y | Y | Y | Y | Y |
| K-P F-stat | 10.34 | 26.86 | 9.33 | 27.51 | 9.33 | 27.51 |
| Clusters | 91 | 91 | 85 | 85 | 85 | 85 |
| Observations | 103,134 | 103,134 | 48,326 | 48,326 | 48,326 | 48,326 |

Notes: Table reports 2SLS estimates. Unit of observation is a DHS respondent. *Beating Free Index* and *Decision Indices* are constructed as explained in main text. Share Cash Crop is the percentage of a district area dedicated to cash crops. All Controls include: Individual Controls (age, dummy for religion, dummy for marital status, number of children, dummy for urban vs. rural status, dummy for household wealth's quantile, household's geographic coordinates), Colonial District Controls (dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices), Pre Colonial Ethnicity level controls (dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid), Distances controls (ethnicity's homeland distance from closest railroad, coast and rivers), and Slave Trade control (log of 1 plus number of Transatlantic and Indian slaves by ethnicity's area). Standard errors clustered at the ethnicity level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 1.15:** Controlling for Christian Missions

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | *Beating Free Index* | | *Decision Index* | |
| Share Cash Crop | 0.344** | 0.170** | 0.557** | 0.238*** |
| | (0.164) | (0.072) | (0.278) | (0.068) |
| FE Country-round | Y | Y | Y | Y |
| FE Current Districts | | Y | | Y |
| All Controls | Y | Y | Y | Y |
| K-P F-stat | 10.30 | 27.53 | 10.30 | 27.53 |
| Clusters | 91 | 91 | 91 | 91 |
| Observations | 103,134 | 103,134 | 103,134 | 103,134 |

Notes: Table reports 2SLS estimates. Unit of observation is a DHS respondent. *Beating Free Index* and *Decision Index* are constructed as explained in main text. Share Cash Crop is the percentage of a district area dedicated to cash crops. All Controls include: Individual Controls (age, dummy for religion, dummy for marital status, number of children, dummy for urban vs. rural status, dummy for household wealth's quantile, household's geographic coordinates), Colonial District Controls (dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices), Pre Colonial Ethnicity level controls (dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid), Distances controls (ethnicity's homeland distance from closest railroad, coast and rivers), and Slave Trade control (log of 1 plus number of Transatlantic and Indian slaves by ethnicity's area). Standard errors clustered at the ethnicity level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 1.16:** Men's Human Capital and Labour Force Participation

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | Panel A: Education | | | |
| | Women Sample | | Men Sample | |
| Share Cash Crop | 0.335* | 0.222** | 0.021 | 0.041 |
| | (0.180) | (0.088) | (0.086) | (0.070) |
| | Panel B: Labour Force Participation | | | |
| | Women Sample | | Men Sample | |
| Share Cash Crop | 0.066 | 0.036 | 0.053* | 0.054*** |
| | (0.048) | (0.032) | (0.029) | (0.018) |
| FE Country-round | Y | Y | Y | Y |
| FE Current Districts | | Y | | Y |
| All Controls | Y | Y | Y | Y |
| K-P F-stat | 10.34 | 26.86 | 9.33 | 27.51 |
| Clusters | 91 | 91 | 85 | 85 |
| Observations | 103,134 | 103,134 | 48,326 | 48,326 |

Notes: Table reports 2SLS estimates. Unit of observation is a DHS respondent. Education is measured in years of education. Labour force Participation is a dummy equal to 1 if a men was employed in the last 12 months before the survey. Share Cash Crop is the percentage of a district area dedicated to cash crops. All Controls include: Individual Controls (age, dummy for religion, dummy for marital status, number of children, dummy for urban vs. rural status, dummy for household wealth's quantile, household's geographic coordinates), Colonial District Controls (dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices), Pre Colonial Ethnicity level controls (dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid), Distances controls (ethnicity's homeland distance from closest railroad, coast and rivers), and Slave Trade control (log of 1 plus number of Transatlantic and Indian slaves by ethnicity's area). Standard errors clustered at the ethnicity level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 1.17:** The Marriage Market

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | *Beating Free Index* | *Decision Index* | *Beating Free Index* | *Decision Index* | *Beating Free Index* | *Decision Index* |
| Panel A: Without Current District Fixed Effects | | | | | | |
| Share Cash Crop | 0.172 | 0.926* | | | 0.059** | 0.019 |
| | (0.176) | (0.472) | | | (0.030) | (0.026) |
| Share Cash Crop Husband | | | -0.076 | 0.616 | | |
| | | | (0.432) | (0.506) | | |
| Panel B: With Current District Fixed Effects | | | | | | |
| Share Cash Crop | 0.200** | 0.295** | | | 0.041 | 0.000 |
| | (0.100) | (0.124) | | | (0.028) | (0.026) |
| Share Cash Crop Husband | | | 0.019 | 0.457 | | |
| | | | (0.343) | (0.413) | | |
| FE Country-round | Y | Y | | | | |
| FE Country-round-wife's ethnicity | | | Y | Y | | |
| FE Country-round-husband's ethnicity | | | | | Y | Y |
| Individual Controls | Y | Y | Y | Y | Y | Y |
| Colonial District Controls | Y | Y | Y | Y | | |
| Pre Col. Ethnicity Controls | Y | Y | Y | Y | | |
| Distance Controls | Y | Y | Y | Y | | |
| Slave Trade Controls | Y | Y | Y | Y | | |
| K-P F-stat | 7.495 | 7.495 | 4.582 | 4.582 | 18.31 | 18.31 |
| Clusters | 78 | 78 | 66 | 66 | 66 | 66 |
| Observations | 18,064 | 18,064 | 18,063 | 18,063 | 18,063 | 18,063 |

Notes: Table reports 2SLS estimates. Unit of observation is a DHS respondent. *Beating Free Index* and *Decision Index* are constructed as explained in main text. Share Cash Crop is the percentage of a district area dedicated to cash crops. Individual Controls: age, dummy for religion, dummy for marital status, number of children, dummy for urban vs. rural status, dummy for household wealth's quantile, household's geographic coordinates – relative to wives in columns 1-6; Colonial District Controls: dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices – relative to wives in columns 1-2, to husbands in columns 3-6; Pre Colonial Ethnicity Controls: dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid – relative to wives in columns 1-2, to husbands in columns 3-6; Distance Controls: ethnicity's homeland distance from closest railroad, coast and rivers – relative to wives in columns 1-2, to husbands in columns 3-6; Slave Trade Controls: log of 1 + number of Transatlantic and Indian slaves by ethnicity's area – relative to wives in columns 1-2, to husbands in columns 3-6. Standard errors clustered at the ethnicity level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 1.18:** Using Instrument following Alesina et al.'s (2013) Approach

| *Dependent Variable* | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| *Beating Free Index* | 0.205*** | 0.068** | 0.164** | 0.133*** | 0.151*** | 0.162*** | 0.401 | 0.298* |
| | (0.05) | (0.03) | (0.08) | (0.05) | (0.06) | (0.05) | (0.26) | (0.17) |
| *Decision Index* | 0.162*** | 0.010 | 0.177* | 0.055 | 0.051 | 0.112** | 0.542 | 0.230* |
| | (0.06) | (0.03) | (0.10) | (0.05) | (0.06) | (0.05) | (0.37) | (0.13) |
| *Education* | 0.391*** | 0.081** | 0.387*** | 0.229*** | 0.223** | 0.302*** | 0.571* | 0.497** |
| | (0.10) | (0.04) | (0.13) | (0.08) | (0.11) | (0.09) | (0.34) | (0.25) |
| *Labour Force Participation* | 0.022 | -0.021 | 0.027 | -0.004 | -0.022 | 0.007 | 0.150* | 0.114* |
| | (0.02) | (0.01) | (0.02) | (0.02) | (0.02) | (0.02) | (0.09) | (0.07) |
| FE Country-round | Y | Y | Y | Y | Y | Y | Y | Y |
| FE Current Districts | | | | | | | | Y |
| Individual Controls | | Y | | | | | Y | Y |
| Colonial District Controls | | | Y | | | | Y | Y |
| Pre Col. Ethnicity Controls | | | | Y | | | Y | Y |
| Distance Controls | | | | | Y | | Y | Y |
| Slave Trade Controls | | | | | | Y | Y | Y |
| K-P F-stat | 34.43 | 27.90 | 8.750 | 34.07 | 19.39 | 34.52 | 3.908 | 5.058 |
| Clusters | 91 | 91 | 91 | 91 | 91 | 91 | 91 | 91 |
| Observations | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 | 103,134 |

Notes: Table reports 2SLS estimates. Unit of observation is a DHS respondent. Outcome variables and the instrument are constructed as described in the main text. Individual Controls: age, dummy for religion, dummy for marital status, number of children, dummy for urban vs. rural status, dummy for household wealth's quantile, household's geographic coordinates; Colonial District Controls: dummy for Islam as main religion, population density in 1930, district area, number of pre colonial conflicts by area, dummy for major vegetation type, ruggedness, number of diamond mines by area, general land quality indices; Pre Colonial Ethnicity Controls: dummy for bride price, dummy for polygyny, dummy for descent system of matriliny, dummy for agriculture as main subsistence activity, Murdock year of observation and coordinates of ethnicity homeland's centroid; Distance Controls: ethnicity's homeland distance from closest railroad, coast and rivers; Slave Trade Controls: log of 1 + number of Transatlantic and Indian slaves by ethnicity's area. Standard errors clustered at the ethnicity level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

# Chapter 2

# Sailing Speed and the Chronometer

**Joint with Luigi Pascali**[1]

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## 2.1 Introduction

Transport improvements are among the key engines of economic growth (Feyrer (2009), Baum-Snow et al. (2016), Donaldson and Hornbeck (2016), Alvarez-Palau et al. (2017), Pascali (2017), Donaldson (2018), Feyrer (forthcoming)). A transport revolution took place at the turn of the nineteenth century, starting in Europe and then spreading to the rest of the world (Bogart (2013)). In these years the productivity of ocean shipping increased, leading to trade and income growth (Frieden (2007), Rönnbäck (2012)), which triggered the beginning of the first wave of globalisation. Though there is an extended literature examining the causes of globalisation (O'Rourke and Williamson (1999), Estevadeordal et al. (2003), Jacks et al. (2011)), little empirical research has yet examined which technologies determined the rise in shipping productivity. The nineteenth century also witnessed the diffusion of one key invention in maritime technology: the chronometer. The chronometer was a novel watch that could measure time with great precision, a necessary condition for determining longitude when navigating. This horological breakthrough solved the centuries-long problem of precisely measuring longitude at sea, and made previous methods that were either inaccurate or based on celestial navigation obsolete (Sobel (1995)).

In this paper, we link the chronometer to the productivity of ocean shipping by focusing on shipping speed. We provide empirical evidence that one of the main causes of the increase in shipping speed is the use of the chronometer to determine longitude at sea. We show that shipping speed is affected more in areas where the sky is often overcast by clouds, which can be reconciled with the fact that the chronometer's main advantage is to enable navigators to measure longitude without having to rely on observations of celestial bodies.

We use the Climatological Database for the World's Oceans (CLIWOC), which collects daily data on worldwide voyages taking place during the eighteenth and nineteenth centuries. CLIWOC reports information for almost 5,000 voyages directly from ships' logbooks, including information on daily position, weather conditions encountered, and ships, but not on the actual presence of chronometers on ships. We supplement these data with climatological information on worldwide cloud coverage, in order to study the differential effect of the chronometer on cloudy routes on which navigators could not find their bearings with the stars.

Using an estimation framework with fixed effects for years, grid cells and ships, we find that, after the introduction of the chronometer, ships begin navigating more often throughout overcast maritime areas relative to previous decades, and that they also travel faster on average on these routes. We argue that this is the result of the adoption of the chronometer, which makes it unnecessary to rely on the observation of celestial bodies such as moon or stars in order to estimate longitude. To support these results, we control for wind speed and direction that would affect ship's routes, and we take into account the seasonality of sailing. Further, we look at changes in sailing speed within ships across time to test the robustness of these findings.

Longitude at sea is easier to determine when a known landmark is in sight without aid of the chronometer or celestial observations. Accordingly, coastal navigation should not be affected by the usage of chronometers. We estimate the effect of the introduction of the chronometer on ship travel and speed separately for coastal and non-coastal navigation, finding only minimal effects of the chronometer on a sample of voyages within 15 kilometres from coast.

CLIWOC includes information on weather dead reckoning is used to determine longitude. In dead reckoning, the navigator finds his position by measuring the course and distance he has sailed from some known point. Although still used until the end of nineteenth century, this method was highly inaccurate, since wind patters and ocean currents could not be taken into account while estimating the drift and the distance covered. We show that logbook's recordings using dead reckoning to measure longitude decrease through time both in absolute and relative terms, and that the likelihood of using this method for daily recordings decreases after the introduction of the chronometer, particularly on the most overcast zones. We conclude that the chronometer adoption influenced shipping speed throughout the nineteenth century, and thus contributed to the development of the transport revolution.

This paper contributes to several strands of literature. First, it adds to the literature on the productivity of ocean shipping prior to the nineteenth century.[2] A common approach in this literature is the use of freight rates to proxy for productivity growth. Several papers focus on Atlantic trade during the early modern period and find that ocean freight rates declined (North (1958), Shepherd and Walton (1972), Harley (1988), Menard (1991)).[3] These studies, however, all focus only

[2]Shipping productivity otherwise drastically improved with the introduction of the steamship during the second half of the nineteenth century (Pascali (2017)).

[3]However, these papers do not link the decline in freight rates to technological advancements. To explain the constant fall in freight rates in the North Atlantic route from 1600 to 1850, North (1968) refers to the increased specialisation permitted by larger markets, the development of backhaul freight, lower turnaround times, and smaller crews allowed by the suppression of piracy. Harley (1988), on the other hand, attributes the fall to denser packing of cotton bales. However, as highlighted in Bogart (2018), Harley used different freight rates series and price deflator, making results not directly comparable.

on Atlantic trade, and whether results hold for other shipping routes is not clear (Harley (1988), Menard (1991)). Moreover, using freight rates to proxy for productivity growth makes results difficult to compare, as it introduces problems of currency conversions and non-standardised weights and measures.

For these reasons, a second branch of this literature looks at shipping speed in order to uncover information on productivity growth. Shepherd and Walton (1972) find no speed increase for the American ships in the sample used. Yet, the sample of ships in this study might not be representative of American shipping, as the authors do not specify which vessels from their source they use, and thus do not address selection bias. Klein (1978) and Morgan (1993), instead, examine the routes crossing the Atlantic and find an increase on ship speed. However, neither study looks at the role played by geographical patterns. In this paper, we not only take geographical and climatological factors into account, but we also exploit them in a regression framework to detect causal effects. More recent studies on sailing speed, such as Rönnbäck (2012), Solar (2013), and Kelly and Ó Gráda (2019), find that ships in their respective samples become faster between the eighteenth century and the beginning of the nineteenth century.[4] These papers all conclude that the reduction in shipping time is a consequence of improved naval technology, specifically in ship design. Among other factors, they mention ships' copper sheathing and improvements in the construction of the hull. In a companion paper, Kelly and Ó Gráda (2017) claim that improved navigation during the early Industrial Revolution owes little to precise longitude estimation and therefore to the adoption of the chronometer. However, the authors do not provide quantitative evidence in support of their argument, and mainly rely on the fact that chronometers were too expensive and inaccurate to back their claim. Our contribution to this literature is twofold. First, we gather more historical accounts on the diffusion of chronometers, and all conclude that the demand for chronometers was satisfied by 1840, indicating that chronometers became affordable during the first half of the nineteenth century (Davies (1978), Dick (2003), Johnston et al. (2015)). Second, we show in an empirical framework that shipping times fall disproportionally for routes crossing particularly overcast areas and further away from the coast, suggesting that more precise methods of estimating longitude play a larger role in these improvements.

Increased shipping productivity enables trade growth and thereby international specialisation, therefore our findings on the reduction in shipping times are also linked to the literature on the first wave of globalisation. This large litera-

[4]With the exception of voyages of the Dutch East India company both in Solar (2013) and Kelly and Ó Gráda (2019).

ture has concluded that globalisation first started during the nineteenth century (O'Rourke and Williamson (1999), O'Rourke and Williamson (2002), Findlay and O'Rourke (2003)). However, this is partly due to the lack of data available on market integration prior to this period. Our results reinforce these findings, and show in particular the possible market integration of countries previously more remote from each other because of particularly unfavourable weather conditions along the sea routes connecting them.

Third, this paper contributes to the literature on watch manufacturing. There exists an extensive literature on how the industry rose with a particular focus on England (Thompson (1967), Cipolla (1970), Landes (1983)). A recent paper by Kelly and Ó Gráda (2016) throws a particular emphasis on this industry by highlighting that in England the process of sustained technological progress in this sector dates back to at least the late seventeenth century. This is used as suggestive evidence that the Industrial Revolution began far earlier than the widely accepted mid-eighteenth century. This literature also includes detailed qualitative essays on the history and diffusion of the chronometer, for example Britten (1894), Britten (1934), May (1976), and Landes (1983). While this literature acknowledges the importance of chronometer, yet no empirical research has examined its role in shaping navigation. We complement this research by quantifying for the first time the importance of the chronometer for downstream technological progress in a sector of major importance, the shipping industry. We provide empirical evidence to support the qualitative literature in concluding that chronometers revolutionised ocean shipping during the nineteenth century.

In the next section we outline the historical background, describing the different methods sailors have used to measure longitude at sea throughout time. In section 3, we provide a detailed description of the data used for the analysis. In section 4, we lay out the empirical strategy and focus on the main results, investigating the effect of the adoption of the chronometer on shipping times. We present additional results and robustness checks in section 5, and in section 6 the conclusions.

## 2.2 Historical Background

Precise estimation of a ship's position at sea was essential for many purposes: exploring new territories, waging wars, developing strategic battle plans and transporting goods between foreign countries and colonies (The Longitude Act (1714)[5],

[5]The Longitude Act 1714, c. 14, HM Parliament, 1714.

Mahan (1890)). Anecdotal evidence bears witness to the catastrophic consequences of sailors being lost at sea because of their inability to orientate, including being shipwrecked and suffering under poor health conditions on board (Nockolds (1963), Nicholls (2008)).

To determine one's location at sea, measurement of latitude and longitude are both needed. Finding latitude has always been relatively simple, since it is the arc of the Meridian north or south of the Equator. All celestial bodies culminate on every meridian during the Earth's daily revolution and, provided the angular height of one of those bodies above the equator was known and its altitude above the horizon could be observed at culmination, latitude could be found.[6] Throughout history, sailors have usually taken the sun as the reference celestial body to measure latitude (Hewson (1951)).

However, to precisely measure longitude, the sun alone is not sufficient and knowledge of time becomes necessary. The "mean sun" travels at a constant rate, covering 360° of arc in 24 hours (Harbord (1883)).[7] Therefore, the link between longitude and time is straightforward: each 15 degrees of longitude correspond to one hour. By knowing the time at one's current position and the time at a reference location, it is thus possible to determine longitude. Knowledge of the current time at sea has always required a simple angular observation of the sun. However, for centuries, sailors struggled to determine the time at the reference point, making it impossible to measure the longitude.

The need for such an invention was so urgent that most of the great maritime nations invited tenders for developing a practicable method to measure longitude at sea (Sobel (1995)). Particularly famous is the Longitude Act, passed by the British Parliament in 1714, with the purpose of creating the Board of Longitude and offering a large monetary reward for a practicable and useful means of determining longitude (The Longitude Act (1714), Burton and Nicholas (2017)). It took several decades, scientific minds, laborious astronomical computations, and technological innovations to develop a suitable and precise method to solve this problem: the chronometer.

In what follows, we briefly describe the methods used to determine longitude until the early eighteenth century, and the most prominent and competing methods promoted during the eighteenth and nineteenth centuries: the lunar distance method and the chronometer. The empirical strategy that we use to estimate the

[6]In observational astronomy, culmination is the instant of time in which the heavenly bodies in their diurnal revolution attain their greatest altitude above the horizon (Harbord, 1883, p.119).

[7]The mean sun is an imaginary sun moving along the celestial equator at a constant rate and completing its annual course in the same time as the sun takes to move round the ecliptic at a varying rate. It is used in the measurement of solar time.

importance of the chronometer relies on the main difference between these two competing methods, while the lunar distance method relied on clear night-time sky to observe reference stars, the chronometer did not, allowing navigators to be able to determine longitude under any weather condition.

### 2.2.1 Predecessors of Lunar Distance Method and Chronometer

#### Dead Reckoning

Dead reckoning is one of the oldest methods of navigation, developed before the Columbian era by Mediterranean navigators. It was the primary method of determining longitude available to mariners before the development of the marine chronometer and the lunar distance method (Taylor (1949)), and largely used by seafarers in the Age of Exploration (Johnston et al. (2015)). With this method, one's current position is calculated based on a known position, or fix, which is then advanced, mathematically or directly on a chart, by means of recorded heading, speed, and time. However, dead reckoning was also highly inaccurate, since wind patters and ocean currents could not be taken into account while estimating the drift and the distance covered.[8] Because the inaccuracy increased with the time spent at sea and distance travelled, celestial observations were taken intermittently, when possible, to determine a more reliable position from which a new dead reckoning began.

#### Eclipses and Occultation

As eclipses are predictable, astronomers have proposed numerous methods to determine longitude by observing these events. Eclipses of Jupiter's satellites became a frequent method used at sea after the beginning of the seventeenth century, when the telescope was invented and Galileo Galilei discovered the four principal satellites of Jupiter (Littlehales (1909)). Even though this approach became more and more accurate with time, it was soon abandoned because the use of telescopes was difficult at sea and relied on good weather conditions during rare events. Another way of measuring longitude during the early eighteenth century was through occultation of planets and stars by the Moon, but it was soon superseded by a more accurate method also developed during that century: the lunar distance method.

[8] To determine the distance navigators relied on the time between two recordings and the ship speed. Measuring speed was often done with a log-line. The log-line method measured the speed of the ship relative to the surface water but provided no means to estimate how fast the water itself flows, therefore not accounting for the effects of surface currents.

### 2.2.2 Lunar Distance Method

The lunar distance method relied on the moon's apparent motion relative to a fixed set of stars. Even though John Werner developed the initial concept already in 1514, its major development is to be attributed to Tobias Mayer, who in the mid-eighteenth century wrote detailed tables predicting the moon's position. To determine his longitude a sailor had to, first, determine his local time through angular observation of the sun. Then, at night, he had to determine time at a reference location by measuring the angle between the centre of the moon and one star chosen from a fixed list, along with their altitudes, correct the moon's position for the twin effects of parallax and refraction, and finally, consult scientific tables and almanacs to check how his measurements translated to a time at a reference location.[9]

Although supported by famous authorities, such as the Astronomer Royal in the United Kingdom, the lunar approach suffered from several drawbacks. The biggest one was that it depended on weather conditions. Without a clear sky, sailors struggled to observe the position of the moon and the stars, making the absence of clouds necessary to pinpoint longitude. Another source of inaccuracy was that from a daytime solar reading to a night-time reading of the lunar distance, a period of six to eighteen hours could pass, and a sailor needed to posses a timekeeper (a simple watch, not a chronometer) good enough to keep precise time over many hours (Landes (1983)). Consulting the almanacs to make careful predictions would also take no less than four hours, making it difficult to take multiple observations per night to increase accuracy (Sobel (1995)). Finally, the whole process required navigators to have highly specialised training. Using the words of Captain Lecky in 1881:

*"To be able to place any reliance on Lunars, requires really a first class observer, and constant practice, and even then the results are at best but approximate"* (Lecky, 1881, p.279).

### 2.2.3 Chronometer

The first manuscript concerning the construction of a chronometer was proposed by a Yorkshire carpenter named John Harrison to the Board of Longitude in 1730, as an alternative to the lunar distance method. The first three prototypes were presented

[9] The almanacs gave lunar distances as they would appear if the observer were at the centre of a transparent Earth. Because the moon is much closer to the Earth than the stars, the position of the observer on the surface of the Earth shifts the relative position of the moon by up to an entire degree (Duffett-Smith (1988) and Montenbruck and Pfleger (2013)).

to the Board in 1735, 1739 and 1757, respectively. They were fairly large clocks, ranging in height from 59 centimetres to 66 centimetres. They were also heavy. For instance, Harrison's second piece weighed 40 kilogrammes (National Maritime Museum, Greenwich (London)). Finally, after almost thirty years from the initial manuscript, in 1759 Harrison presented his prize-winning longitude chronometer, H4, which was only 13 centimetres in diameter and weighted 1.45 kilogrammes.

This mechanical timepiece was capable of maintaining precise time even when sea conditions were not favourable for navigation. The pendulum, its rival on land, was debarred by the ship's motion and by the difference in gravity at different latitudes (Hewson (1951)). Further, Harrison's chronometer was superior to normal watches as it was built in such a way that the outside temperature could not affect any mechanical component, making it the most accurate instrument to determine longitude at sea the Board of Longitude had then received.[10]

The chronometer, unlike the lunar method, benefited from several advantages. It did not require any special knowledge to be consulted: everything a sailor had to do was comparing his local time at sea, determined by angular observation of the sun, and the time at the reference point as indicated by the chronometer. Given that sailors were provided with accurate tables with the declinations of the sun during the day, local time at sea was not difficult to measure as the sun, differently from the other stars, is more visible even with overcast sky, and especially at high latitudes it often appears even on cloudy days (Jones and Stainer Clarke (1799)). No night-time observations were needed, and therefore no reliance on clear skies either: navigators could orientate themselves regardless of the presence of clouds. Moreover, the much shorter time required for this procedure allowed navigators to take multiple longitude recordings per day, increasing precision.

Despite its advantages, the adoption of the chronometer was a relatively slow process, initially hampered by the high production costs.[11] There is little data on the number of chronometers aboard ships, but it is commonly accepted that survey and exploratory vessels were the first to be equipped with them by the end of the eighteenth century (May (1976)), followed by war and merchant ships, which gradually adopted chronometers through the 1820s and 1830s.[12] Looking

[10] Changes in temperature cause the expansion and contraction of different parts of the mechanism of a watch. Chronometers were furnished with an expansion balance formed by a combination of metals of different expansive qualities (as brass and steel) which effects the compensation required (Harbord, 1883, p.54).

[11] Landes (1983) reports that in England, around 1815, a good chronometer cost anywhere from twenty-five to hundred pounds: from half a years' to two years' salary for a skilled worker.

[12] An exception is the East India Company, which adopted the chronometer in large numbers already during the 1790s (May (1976), Davies (1978)).

at timekeepers on warships of the time, the number of ships with chronometers in the French Royal Navy rose from 34 in 1815 to 143 in 1832, while the US Navy had only 54 in 1835, the Dutch Navy 18 in 1815 but 85 two decades later, and the British Royal Navy went from 130 in 1821 to 253 in 1835.[13] For the British Royal Navy, it is generally accepted that 1825 was the breakthrough year for ships to be equipped with at least one chronometer each (Britten (1894), May (1976), Dick (2003), Johnston et al. (2015)). Looking at vessels overall, various accounts reach the consensus that the market for chronometers was saturated by 1840 (Davies (1978), Dick (2003), Johnston et al. (2015)).

In the analysis of Section 4, we empirically infer the years of the diffusion of chronometers. We use data on locations of ships from logbooks covering the end of the eighteenth century and the start of nineteenth century, together with information on weather conditions. Our results support the timeline proposed by the written evidence mentioned, finding the decade between 1825 and 1835 particularly important for the chronometer's adoption.

## 2.3 Data

The analysis in this paper is based on a dataset covering roughly 4,700 voyages across the globe during the eighteenth and nineteenth centuries, which we merge with additional geographical data on cloud coverage and wind patterns. This section outlines the data sources and the process followed to construct the main variables.

### 2.3.1 Navigation during the 18$^{\text{th}}$ and 19$^{\text{th}}$ Century

To study the effect of the chronometer on ship speed during the eighteenth and nineteenth century, we use the CLIWOC dataset, which contains information on actual routes and voyages collected from logbooks of different European countries in the period 1750-1855.[14] CLIWOC consists of more than 285,000 daily logbook entries from ships of the British, Dutch, French, and Spanish navies, and British and Dutch East India Companies. The digitised logbooks do not represent the entirety of the logbooks produced over the century covered. The CLIWOC authors estimate they might be less than 10 percent. Also, different nationalities are over-represented during different periods of time in an attempt to keep the number of voyages roughly

[13] Information on the French Royal Navy can be found in Boistel (2010) and Johnston et al. (2015), on the Dutch Navy in Davids (1986) and Leopold (1996), on the US Navy in Johnston et al. (2015), and on the British Royal Navy in May (1976) and Davies (1978).

[14] CLIWOC contains a few voyages for the seventeenth century as well. In the final analysis sample, before 1750 there are only 10 voyages recorded, with the first one starting in 1662.

constant through the decades, and compensate for the fact that little data is present in the Dutch, French and Spanish archives for the wartime period 1793-1815. This explains why in these decades British voyages are reported in abundance, at the expenses of observations of British ships in later years. Nonetheless, CLIWOC offers a multitude of voyages on different routes across the whole world, which makes it possible to study navigation over a hundred years period in unusual detail.

The data contain information for each voyage's ports of departure and arrival, daily location coordinates, name of ships and their nationality. With these, we construct the outcome variables that we use in Section 4 to understand how navigation changed after the introduction of the chronometer, such as daily speed and number of ships sailing through cloudy locations. Table 2.1 shows summary statistics for the voyages on a cleaned sample.[15] The sample counts a total of 4,759 voyages by 939 different ships: 395 British, 321 Dutch, 73 French and 150 Spanish. The table also shows that the average voyage duration in the whole dataset is 57 days, the average speed is 7.6 kilometres per hour, and the average number of days in between two latitude and longitude recordings is one day.

CLIWOC contains a variable detailing how daily longitude recordings are taken. Almost 90 percent of the observations report either *dead reckoning* (43.32 percent) or *from true navigation (bearing/distance, celestial)* (43.21 percent), while for the remaining 10 percent the recordings are mainly interpolated. While dead reckoning was already explained above, *from true navigation (bearing/distance, celestial)* could have a dual meaning: it could refer to the lunar distance approach or the chronometer, since celestial observations were needed with both.[16] Figures 2.1 and 2.2 present the number of longitude recordings in the dataset using dead reckoning or true navigation for every decade, in absolute numbers and shares, respectively. Both figures show a downward trend in the use of dead reckoning through time and an upward trend of true navigation, confirming what was discussed in the previous section: when the lunar distance method and the chronometer were developed, they superseded dead reckoning as they were both more precise and reliable methods.

[15]The cleaned sample is a subsample of the original CLIWOC dataset in which we dropped recordings if: both latitude and longitude are missing, the computed speed is above/below the 99th and 1st percentile, and a voyage has less than 4 observations in total. The cleaned sample contains 85 percent of the total CLIWOC observations.

[16]With the lunar distance method, longitude measurements depend completely on observing the moon and some stars, while with the chronometer, celestial observations are needed to determine the time at sea of a ship.

### 2.3.2 Climatological Information

CLIWOC contains information on weather conditions such as wind speed and direction, presence of clouds, rain, fog, snow and similar. However, many of these variables are not recorded for every observation, perhaps in a non-random fashion. Moreover, wind speed is often given in words, as for example "moderate intermixed with some flying squalls" or "en veces fresquitos" ("sometimes cool"). Although the CLIWOC authors translate this information into numbers following a standard Beaufort scale, the conversion might differ across authors and the reported wind conditions could be different across sailors' nationalities.[17]

Given these constraints, we use different sources to complement our dataset. We use data from the US National Oceanic and Atmospheric Administration (NOAA) to gather information on average contemporary speed and direction of sea-surface winds, and the NASA Earth Observations (NEO) data on average contemporary cloud coverage.[18] Using contemporary data to proxy for clouds and winds in the eighteenth and nineteenth century requires the assumption that weather is stable over time, at least over the last two hundred years.[19]

We validate this assumption by showing that sailing vessels from CLIWOC follow present-day wind patterns, as shown in Figure 2.3. Regarding clouds, we provide two pieces of evidence. CLIWOC includes two variables containing information on clouds: *CloudFrac*, a numerical variable taking values from 0 to 1 indicating the clouded part of the sky, for which there are 93 observations, and *Clearness*, a non-numerical variable describing the clearness/brightness of the sky, with more than 87,000 observations recorded (ca. 35 percent of the total dataset). Out of these 87,000, 75 percent are from British logbooks. We select only British observations reporting a *Clearness* value repeated in total at least 500 times, ending with slightly more than 45,000 observations divided into six categories: clear, fair, fine, pleasant, hazy, and cloudy. We convert these categories into numerical values comparable with the *CloudFrac* variable, assigning value 0 to clear, fair, fine and pleasant, value

[17] The Beaufort wind force scale is an empirical measure that relates wind speed to observed conditions at sea or on land. It was devised in 1805 by the hydrographer Francis Beaufort.

[18] Data source for wind data: http://woce.nodc.noaa.gov/woce_v3/wocedata_2/sat_mwf/sat_mwf2/. Average monthly data are available from August 1999 to June 2002. Throughout the analysis we use averages across years. Data source for clouds data: https://neo.sci.gsfc.nasa.gov. Average monthly data are available from March 2000 to October 2015. Throughout the analysis we use minimum coverage across years.

[19] Pascali (2017) makes the same assumption regarding the average velocity and direction of the sea-surface winds. Using the same source of wind data (NOAA), he computes sailing times between countries and then compares these optimized routes by sail with a set of actual voyages by sailing ships taken from CLIWOC.

0.5 to hazy, and 1 to cloudy. [20]

To validate CLIWOC cloud coverage information, we then compute the correlation between both *CloudFrac* and the new *Clearness* variable with the cloud coverage data from NEO. The correlations are positive and amount to 0.28 and 0.33. To visualise the data, Figure 2.4 displays the NEO cloud coverage in Panel 2.4a, the new *Clearness* variable in Panel 2.4b, and *CloudFrac* in Panel 2.4c. As shown markedly in Panel 2.4a and 2.4b, clouds from the two datasets follow similar patterns: a more overcast sky on the Northern Atlantic, the Gulf of Guinea, the Southern Atlantic and around Sumatra, and clearer skies on the Caribbean Sea, the coast of Brazil, the North-West and the South-East coast of Africa.

## 2.4 Identification Strategy and Results

### 2.4.1 Timing of the Chronometer's Adoption

Studying the effect of the chronometer in shaping navigation during the eighteenth and nineteenth century requires knowing when the chronometer was adopted. While few anecdotal evidence place the diffusion during the first half of the nineteenth century, with a focus on the 1820s and 1830s, no record of chronometer adoption is available from the CLIWOC dataset.

Therefore, instead of fixing a date for the diffusion of the chronometer *a priori*, we infer the timing by investigating when the presence of clouds stopped deterring ships from navigating through the most overcast places, using the data on worldwide ship voyages from CLIWOC and the cloud coverage data from NEO. We estimate the following equation:

$$\ln(1 + voyages)_{it} = \alpha + \sum_{t=1}^{6} \beta_t Clouds_i + X_{it}\gamma + \delta_i + \delta_t + \varepsilon_{it} \qquad (2.1)$$

where $i$ indexes a one degree latitude by one degree longitude grid cell, $t$ indexes decades, the outcome variable is the logarithm of one plus the total number of voyages passing through a grid cell in a given decade, and the explanatory variable

[20] We use a sample of British voyages as they represent 75 percent of the sample with non missing values in the *Clearness* variable. The remaining 25 percent are recordings from Dutch voyages. Another reason to operate only with British observations is that we can be consistent in the scale used to convert the *Clearness* variable in numbers between 0 and 1. Within British observations, we only use the values repeated at least 500 times since they are easier to be converted into numbers as they can be ranked among each others. Other values, as for example "clear, dark cloudy weather" or "first part cloudy" are more difficult to be categorised even if recorded multiple times.

of interest, $Clouds_i$, represents the cloud coverage of a grid cell as a fraction from 0 to 1 from the NEO data, assumed to be constant over time. To capture how the relationship between cloud coverage and the number of voyages through a cell has changed over time, we allow the coefficient on clouds to vary by decade $t$. $X_{it}$ is a set of covariates: wind and latitude, both interacted with decade dummies to capture how their effects change over time, and seasonality of voyages in every decade, while $\delta_i$ and $\delta_t$ are grid cell and decade fixed effects. Standard errors are clustered at the grid cell level to account for heteroscedasticity and autocorrelation.

Table 2.2 presents the OLS results. All the specifications include grid cell and decade fixed effects, where the period before 1805 is the omitted group.[21] Column 1 reports results for a simple specification that only includes the fixed effects. Starting with the decade 1835-1844 the coefficients on cloud coverage are positive and statistically significant at the 1 percent level, indicating that after 1835 more cloudy areas see a larger increase in ship voyages passing through relative to less cloudy areas.

In columns 2 to 4 we add different control variables. Column 2 adds the average speed and direction of the wind in a grid cell interacted with decade dummies. Since meteorological factors, such as wind and clouds can be correlated, these controls ensure that the coefficients on *Clouds* are capturing only the changing effect of cloud coverage on the number of voyages. Adding these variables does not alter the main results.

Column 3 controls for the absolute level of latitude interacted with decade dummies. This set of variables controls for the changing effect of tropical climate over time, which became standard in economic history and trade after Nordhaus (1994), Theil and Chen (1995), and Hall and Jones (1999). Including them barely change the results.

In column 4, we control for seasonality by adding the percentage of voyages passing through a grid cell in each quarter of every decade. This accounts for the fact that navigation before the steamship was highly seasonal, since navigators were at the mercy of weather once they set sail. These controls do not alter the main results.

Finally, column 5 presents results when controlling for all variables together. Results remain mostly unchanged: the two decades after 1835 see a sizeable increase in the number of voyages passing through more cloudy zones. The coefficients

[21] We treat the decades between ca. 1745 and 1805 as omitted group as we are mostly interested in time trends in the decades before and after the adoption of the chronometer, while time trends between cloudy and non-cloudy zones further back in the past could be affected by other factors. Moreover, older data might be more noisy.

indicate that a one percent increase in cloud coverage translates on average, for the final two decades, into a 0.57 percent larger increase in the number of journeys passing through a given grid cell, compared to the period before 1805, relative to cells with less average cloud coverage.

These results are obtained using a sample of voyages that only sailed in the open sea. Table 2.3, instead, shows the results of the same regression using only ships sailing close to the coast. Longitude was easy to determine when a known landmark was at sight, without the need of a chronometer. Therefore, coastal navigation should not be affected by the usage of chronometers. CLIWOC provides a variable indicating whether a ship's position is coastal or not. However, as this variable is recorded with considerable measurement error, we supplement these observations by including all records of ships sailing within 15 kilometres from the coast.

The table suggests that, regardless of the specification used, there is no statistically significant change in the effect of cloud coverage on number of voyages close to the coast, in support of the argument outlined above. Further, the coefficients in the most preferred specification of column (5) are all negative, differently from the ones in the open sea sample. To better visualise the results, Figures 2.5 and 2.6 plot the coefficients of the more conservative specification of column 5 respectively for the open sea and coastal samples.

Putting together this empirical evidence and the few written sources placing the diffusion of the chronometer during the 1820s and 1830s, we consider 1825-1834 as the decade of chronometers diffusion and adoption. In the rest of the text, we will thus define the "post" period as the years after 1830, taking the middle year of the diffusion's decade as the turning point, and the "pre" period as the years before 1830.[22]

In Appendix A, we present additional tables using an event-study approach to estimate the effect of the adoption of the chronometer on the number of voyages passing through overcast areas. Instead of inferring from the data the decade in which the chronometer is adopted, we set it to be 1825-1834, following the few evidence from the literature. However, this approach is less agnostic on the adoption timing and it imposes more structure to the data. As shown in table 2.6, by omitting the decade 1825-1834, the coefficients on the two subsequent decades, 1835-1844 and 1845-1855, are positive and statistically significant always at the 1 percent level. Looking at column 5, which presents the results of a regression with all controls and fixed effects, the coefficients for the three decades before the chronometer's diffusion,

[22] All the results are robust to considering "post" period as the decades after 1835, and the "pre" period as the decades before 1825. Results available on request.

from 1795 to 1824, do not show statistically significant coefficients, validating the parallel trends assumption for this period. Before 1795, a few decades have statistically significant coefficients, however, mostly with a negative sign and half in size. Overall, since further back in time data could also be more noisy, it is difficult to draw solid conclusions from the first decades. Table 2.7 of the same appendix shows the results for the coastal sample, where no effect of the chronometer's adoption on the number of voyages through overcast places is detected.

### 2.4.2 Sailing Speed and the Chronometer

Having defined when the chronometer was adopted, we now investigate the role of this invention on sailing speed. To capture this relationship, we estimate the following equation:

$$\ln(1+speed)_{ist} = \alpha + \sum_{q=1}^{8} \beta_q^1 CloudsQnt_i + \sum_{q=1}^{8} \beta_q^2 (CloudsQnt_i \times Post_t) + X_{it}\gamma + \delta_t + \varepsilon_{ist} \tag{2.2}$$

where $i$, $s$ and $t$ index for grid cell, ship and year. The outcome variable is the logarithm of one plus the speed, in kilometres per hour, of a ship crossing through a grid cell in a given year, $CloudsQnt_i$ are eight dummies representing quantiles $q$ in the distribution of cloud coverage, $Post_t$ is a dummy taking value one for the years after 1830, and, as previously, $X_{it}$ are controls for wind force and direction, quarter of the year and absolute level of latitude. The quantile distribution of cloud coverage is shown in Table 2.8 of Appendix A. The regression also includes year fixed effects, $\delta_t$, to take into account other improvements in navigation techniques that happened over these years (Kelly and Ó Gráda (2019)). As previously, standard errors are robust and clustered at the grid cell level.

Table 2.4 presents the results. All specifications include year fixed effects, and use as omitted category of cloud coverage the fourth quantile (30-34 percent cloud coverage per grid cell). Column 1 reports results for a simple specification that only includes fixed effects. The results indicate that in areas in which average cloud coverage is higher, as in quantiles 6 to 8, ship speed increases more strongly in the post period compared to the pre period.

Columns 2, 3 and 4 include, respectively, controls for wind force and direction, absolute level of latitude, and year's quarters, all interacted with the post dummy. Added one by one, these variables do not alter the results, leaving the coefficients on the last three cloud quantiles always positive and statistically significant at the 1 percent level.

In column 5, we add the three sets of controls together and the results remain the same: relative to the period before chronometers, ships sailed faster in more cloudy routes, with the biggest increase in speed of 0.16 kilometres per hour, or an additional 2.10 percent increase, with respect to the mean ship speed, in more cloudy areas.[23]

The last column reports the results when also including grid cell fixed effects. This specification controls for any unobservable time-invariant geographic feature that could affect shipping speed at a certain place in the sea. When adding them the coefficients on cloud quantiles follow a similar pattern up until quantile 7, followed by a drop in magnitude and significance for the last cloud quantile. However, fixing locations through grid cell fixed effects eliminates the effect of ships changing their route in response to the chronometer. For example, if ships realise their new higher speed in grid cells in which they did not navigate before the chronometer, this effect is taken out by the grid cell fixed effects. Furthermore, if slower ships that would not venture into cloudy areas pre-chronometer start doing so after its diffusion, it would also lead to a smaller coefficient estimate. It appears that a substantial part of the speed gains driven by the introduction of the chronometer is associated with a change of routes, which is not surprising given that the chronometer changed fundamentally the possibilities of navigating at high seas. Thus, focusing on within grid cell changes shows only parts of the aggregate effects. Therefore, our preferred specification is the one without grid cell fixed effects for the remaining analysis.

Table 2.5 shows the results of the same equation estimated in the sample of coastal navigation. Throughout the specifications only a few coefficients are significant, without a clear positive increasing pattern, contrary to the non-coastal sample. The coefficients of column 5 in Table 2.4 and 2.5 are plotted in Figure 2.7 and 2.8, in order to better visualise the results: ships navigate faster on more cloudy zones from 1830 onwards relative to the pre period, and especially when further away from the coast. This suggests a positive role of the adoption of the chronometer on ship speed.[24]

To better see where the positive effects shown in the previous analysis come from, we estimate equation 2.2 separately on the pre and the post periods. Figures 2.9 and 2.10 show the coefficients estimated using all the controls, and year fixed effects. Panels (a) display the results on the period before the chronometer while Panels (b) show the relationship for the period after the adoption. The results

[23]Since between the pre and the post period the average ship speed increases by 29.37 percent, the increase of 2.10 percent found accounts for 7.15 percent of the total gain.

[24]Table 2.9 and 2.10 in Appendix A also shows that the results in both samples are robust using standard errors adjusted for two-way clustering within grid cell and ship.

suggest that, with the chronometer (Panels (b)), ship speed does not significantly change depending on cloud coverage. However, clouds slow down navigation in the years before the adoption of the chronometer (Panels (a)), and especially in the sample of ships in open sea. The results of this exercise are also shown in Appendix A in Tables 2.11 and 2.12 for the sample of open sea navigation, and in Tables 2.13 and 2.14 for the coastal one.

## 2.5 Robustness Checks and Additional Results

### 2.5.1 Ship Fixed Effects

Since chronometers were as small as pocket watches, they could easily be brought on board of ships. Therefore, we add ship fixed effects to equation 2.2, in order to exploit the variation in speed within ship, this way comparing the same ship sailing in the pre and post period. CLIWOC contains data on ships' name, nationality and type. However, since information on the type is missing for approximately 42 percent of the dataset, we only use ships' name and nationality.[25]

Tables 2.15-2.20 in Appendix A replicate the results of the previous section adding ship fixed effects to all specifications. As shown, the previous findings are robust to this additional layer of fixed effects. This indicates that the increase in speed in most overcast places is not due to progress in other ship building technology that may have occurred over the time period studied here. This conclusion relies on the assumption that no other shipping innovation occurred at the same time of the chronometer that had a differential effect on shipping speed on more cloudy routes. In the same appendix, Tables 2.15 and 2.16 also show that the results are robust using standard errors adjusted for two-way clustering within grid cell and ship.[26]

### 2.5.2 Coastal Navigation

So far we defined coastal navigation as all ships sailing within 15 kilometres from the coastline. In this subsection, we show that the results on the timing of the chronometer's adoption and on sailing speed are robust to changing the definition of coastal navigation to 5, 10, 30 and 50 kilometres from the coastline.

[25] In the subsample of voyages for which all ships' information is present, substituting name-by-nationality fixed effects with ship type fixed effects does not alter the results.

[26] Note that the coefficient estimates in Table 2.15 drop again in the last column, as already observed in Table 2.4. This indicates that either ships improved their speed in cloudy areas by also adjusting their route, or ships that were fast in non-cloudy areas pre-chronometer also started sailing in cloudy areas after its diffusion, but without speed improvements relative to the average speed in these cells.

Tables 2.21 and 2.22 of Appendix A present the results on the timing of the chronometer's adoption, showing in each column the coefficient estimates when estimating equation 2.1 with all controls and fixed effects, and varying the definition of coast. Using alternative definitions of coastal navigation does not change the results, as shown by the comparison of each column with column 3, reporting the previous findings using 15 kilometres as threshold.

In Appendix A, Tables 2.23 and 2.24, instead, show the results on sailing speed. Similarly, columns 1-6 present the coefficient estimates when estimating equation 2.2, and column 3 reports the previous findings when using 15 kilometres as threshold for coastal navigation. The results for the open sea sample are very similar to the ones in the main analysis. For the coastal sample, instead, the results are different when looking at column 6, which uses 50 kilometres as threshold. With this definition, there is a statistically significant increase in speed for the last three cloud quantiles, mirroring the results obtained in the open sea sample. This could imply that a more accurate definition of coastal navigation is sailing at most 40 kilometres away from the coastline.[27]

### 2.5.3 Dead Reckoning

Given that CLIWOC provides information on the use of dead reckoning to determine the ship longitude, we check whether this method is differently affected by clouds' presence across decades. As previously discussed, dead reckoning was a highly inaccurate method, and whenever possible navigators used celestial observations to measure their longitude more precisely. To check this relationship, we estimate the following regression separately in the pre and post chronometer period:

$$DeadReckoning_{ist} = \alpha + \sum_{q=1}^{8} \beta_q CloudsQnt_i + X_{ist}\gamma + \delta_s + \delta_t + \varepsilon_{ist} \qquad (2.3)$$

where $s$, $i$, and $t$, index ship, grid cell and year. $DeadReckoning_{sit}$ is an indicator variable equal to 1 if this method was used to measure longitude in a given recording, $CloudsQnt_i$ are eight dummies representing quantiles $q$ in the distribution of cloud coverage, $X_{it}$ are controls for wind force and direction, quarters of the year and absolute level of latitude, while $\delta_t$ and $\delta_s$ are year and ship fixed effects. Standard errors are robust and clustered at the grid cell level.

Figures 2.11 and 2.12 present the coefficients on the cloud quantiles in the most conservative specification, adding all controls and fixed effects, in the open sea

[27] All these findings are robust to using ship fixed effects (results available on request).

and in the coastal sample. For the sample of open sea voyages, in the pre period the use of dead reckoning increases with cloud coverage, indicating that when celestial observations are not possible, navigators rely more on dead reckoning, even though it is an inaccurate method. However, this relationship weakens in the post period, as dead reckoning is barely used, even in the presence of clouds. A different story is shown in the sample of coastal voyages, where there is no relationship between cloud coverage and dead reckoning in either period, as there is no need to use it when landmark is at sight.

## 2.6 Conclusion

In this paper, we estimate the timing of the diffusion of the chronometer, one of the great technological innovations in maritime transportation, which allowed sailors to determine their precise longitude at sea. We exploit worldwide cloud coverage, and its differential effect over time, to support the written sources placing the chronometer diffusion during the 1820s and 1830s.

Further, we study the effect of the chronometer on shipping speed, one of the main determinants of ocean shipping productivity. We find that after the introduction of chronometers, ships start navigating faster in more cloudy places relative to the period before. We find that once chronometers are available, ship speed does not vary with overcast sky, while clouds do slow down navigation in the years before the chronometer.

To support the robustness of these findings, we show that they do not hold in a sample of only coastal navigation, as finding longitude was easy when land was in sight. We also back up our argument by exploiting variation in sailing speed within the same ship over time, relying on the assumption that no other shipping innovation that occurred at the same time of the chronometer had a differential effect on shipping speed on more cloudy routes.

This work contributes to the literature on ocean shipping productivity and the transport revolution that started in Europe by the end of the nineteenth century and then spread out to the rest of the world (Bogart (2013)). Despite the work that has already been done to document the changes in shipping productivity and speed (North (1958), Klein (1978), Harley (1988), Morgan (1993), Rönnbäck (2012), Kelly and Ó Gráda (2019)), none of them focus on the crucial role of precise longitude estimation. Our work supplements this literature by providing new empirical insights on the positive relationship between the chronometer and shipping speed.

This paper also speaks to the literature on watch manufacturing. This literature focuses on the history of watches (Thompson (1967), Cipolla (1970), Landes (1983)), and on the evolution of their prices in light of sustained innovation since pre-industrial times (Smith (1976), Kelly and Ó Gráda (2016)). However, not much has been done to investigate how this innovation benefitted productivity in other sectors. We quantify for the first time the relevance of the timekeeper for downstream technological progress in a sector of major importance such as the shipping industry.

The findings of this paper suggest future work in at least two directions. In their original copies, the logbooks digitised in CLIWOC contain information on daily chronometer use. Since CLIWOC provides logbook identification numbers and names of the archives where they are kept, it would be possible to find the original copies at British, Dutch, French, and Spanish archives and search for information on the use of chronometers on every ship, day by day. This would allow a detailed analysis of the effect of the chronometer in shaping navigation in a difference-in-difference framework. Second, the reduction in shipping times during the eighteenth and nineteenth centuries is often linked to the first wave of globalisation. Therefore, studying the relationship between the adoption of the chronometer and trade patterns could also shed light on the mechanisms throughout which globalisation spread around the world. In line with this agenda, we have begun the digitisation of a new historical trade dataset by collecting bilateral trade data from archival sources. So far, we have gathered more than 17,000 observations, for more than 750 country pairs, covering the 77 years between 1784 and 1860.

## 2.7 Tables

**Table 2.1:** Summary Statistics: Voyages

| | *Mean* | *St Dev* | *Min* | *Max* | *N* |
|---|---|---|---|---|---|
| Voyages | | | | | 4,759 |
| Ships (total) | | | | | 939 |
| British | | | | | 395 |
| Dutch | | | | | 321 |
| French | | | | | 73 |
| Spanish | | | | | 150 |
| Duration per voyage (days) | 57.431 | 45.935 | 4 | 299 | 4,759 |
| Days per recording | 1.004 | 0.131 | 0 | 3 | 244,414 |
| Speed (km/h) | 7.668 | 3.956 | 0.613 | 17.844 | 233,969 |

Note: *Voyages* is number of distinct voyages kept for the analysis; *Ships* is the number of distinct ships kept for the analysis; *Duration per voyage* is the number of days in a voyage between the last and the first logbook recordings; *Days per recording* is the number of days passing between distinct longitude and latitude recordings; *Speed* is the speed in kilometres per hour as calculated by the authors. *Days per recording* and *Speed* have different total observation numbers because of missing values for the *Speed* variable (which is calculated as distance covered over time used, and distance can not be measured when latitude or longitude recordings are missing).

**Table 2.2:** Voyages and Clouds over Time - Open Sea Sample

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Dependent variable:* | *ln(1+Number of travels)* | | | | |
| Clouds × I(1805-1814) | -0.107* | -0.087 | 0.049 | -0.114** | 0.043 |
| | (0.06) | (0.06) | (0.06) | (0.06) | (0.06) |
| Clouds × I(1815-1824) | -0.018 | -0.007 | 0.151*** | -0.020 | 0.148** |
| | (0.06) | (0.06) | (0.06) | (0.06) | (0.06) |
| Clouds × I(1825-1834) | -0.109* | -0.060 | 0.094 | -0.121* | 0.085 |
| | (0.06) | (0.06) | (0.07) | (0.06) | (0.07) |
| Clouds × I(1835-1844) | 0.546*** | 0.573*** | 0.679*** | 0.546*** | 0.679*** |
| | (0.08) | (0.08) | (0.09) | (0.08) | (0.09) |
| Clouds × I(1845-1855) | 0.324*** | 0.320*** | 0.448*** | 0.327*** | 0.453*** |
| | (0.07) | (0.07) | (0.08) | (0.07) | (0.08) |
| FE Decade | Y | Y | Y | Y | Y |
| FE Cell | Y | Y | Y | Y | Y |
| Wind Controls × Decade | | Y | | | Y |
| Abs. Latitude × Decade | | | Y | | Y |
| Quarter Controls | | | | Y | Y |
| Clusters | 14,054 | 14,054 | 14,054 | 14,054 | 14,054 |
| Observations | 62,689 | 62,689 | 62,689 | 62,689 | 62,689 |

Note: Table reports OLS estimates. Unit of observation is a grid cell-by-decade. Open Sea Sample refers to logbook recordings at least 15 kilometres away from the coast. The dependent variable is the natural logarithm of 1 plus the number of travels within a grid cell in a decade. Clouds is the fraction of a grid cell covered by clouds, interacted with indicator variables for different decades. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are percentage of travels in a grid cell by quarter-decade. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.3:** Voyages and Clouds over Time - Coast Sample

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Dependent variable:* | *ln(1+Number of travels)* | | | | |
| Clouds × I(1805-1814) | -0.617 | -0.692 | -0.642 | -0.610 | -0.742 |
| | (0.58) | (0.56) | (0.56) | (0.59) | (0.57) |
| Clouds × I(1815-1824) | -0.487 | -0.458 | -0.458 | -0.529 | -0.488 |
| | (0.51) | (0.50) | (0.49) | (0.52) | (0.49) |
| Clouds × I(1825-1834) | -0.137 | -0.223 | -0.218 | -0.154 | -0.330 |
| | (0.55) | (0.54) | (0.54) | (0.55) | (0.54) |
| Clouds × I(1835-1844) | -0.628 | -0.753 | -0.620 | -0.615 | -0.718 |
| | (0.82) | (0.83) | (0.84) | (0.81) | (0.85) |
| Clouds × I(1845-1855) | -0.104 | -0.137 | -0.181 | -0.115 | -0.225 |
| | (0.54) | (0.54) | (0.54) | (0.54) | (0.54) |
| FE Decade | Y | Y | Y | Y | Y |
| FE Cell | Y | Y | Y | Y | Y |
| Wind Controls × Decade | | Y | | | Y |
| Abs. Latitude × Decade | | | Y | | Y |
| Quarter Controls | | | | Y | Y |
| Clusters | 560 | 560 | 560 | 560 | 560 |
| Observations | 1,505 | 1,505 | 1,505 | 1,505 | 1,505 |

Note: Table reports OLS estimates. Unit of observation is a grid cell-by-decade. Coast Sample refers to logbook recordings within 15 kilometres from the coast. The dependent variable is the natural logarithm of 1 plus the number of travels within a grid cell in a decade. Clouds is the fraction of a grid cell covered by clouds, interacted with indicator variables for different decades. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are percentage of travels in a grid cell by quarter-decade. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.4:** Speed and Clouds - Open Sea Sample

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | | |
| Clouds quantile 1 × I(Post) | -0.015 | -0.000 | -0.007 | -0.015 | 0.017 | 0.018 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) |
| Clouds quantile 2 × I(Post) | -0.015 | 0.002 | -0.011 | -0.015 | 0.014 | 0.021 |
| | (0.02) | (0.02) | (0.03) | (0.02) | (0.02) | (0.01) |
| Clouds quantile 3 × I(Post) | 0.003 | 0.004 | 0.003 | 0.002 | 0.004 | -0.001 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) |
| Clouds quantile 5 × I(Post) | 0.007 | 0.032 | 0.004 | 0.007 | 0.031 | 0.016 |
| | (0.03) | (0.02) | (0.03) | (0.03) | (0.02) | (0.01) |
| Clouds quantile 6 × I(Post) | 0.074*** | 0.102*** | 0.072*** | 0.073*** | 0.105*** | 0.042*** |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) |
| Clouds quantile 7 × I(Post) | 0.081*** | 0.127*** | 0.071*** | 0.080*** | 0.117*** | 0.028** |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) |
| Clouds quantile 8 × I(Post) | 0.106*** | 0.160*** | 0.098*** | 0.106*** | 0.161*** | 0.014 |
| | (0.03) | (0.03) | (0.03) | (0.03) | (0.03) | (0.01) |
| FE Year | Y | Y | Y | Y | Y | Y |
| FE Cell | | | | | | Y |
| Wind Controls × I(Post) | | Y | | | Y | Y |
| Abs. Latitude × I(Post) | | | Y | | Y | Y |
| Quarter Controls × I(Post) | | | | Y | Y | Y |
| Clusters | 13,722 | 13,722 | 13,722 | 13,722 | 13,722 | 13,722 |
| Observations | 232,561 | 232,561 | 232,561 | 232,561 | 232,561 | 232,561 |

Note: Table reports OLS estimates. Unit of observation is a grid cell. Open Sea Sample refers to logbook recordings at least 15 kilometres away from the coast. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Post is a dummy variable equal to 1 if the logbook recording is dated after 1830. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

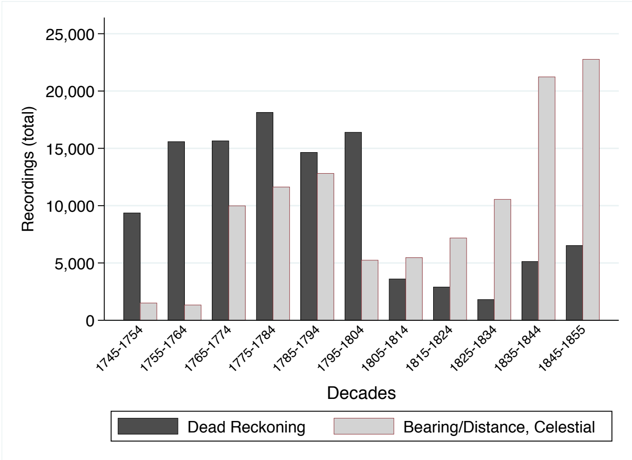
**Table 2.5:** Speed and Clouds - Coast Sample

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | | |
| Clouds quantile 1 × I(Post) | 0.130 | 0.051 | 0.140 | 0.122 | 0.052 | 0.111 |
| | (0.10) | (0.10) | (0.11) | (0.10) | (0.11) | (0.22) |
| Clouds quantile 2 × I(Post) | 0.361*** | 0.287** | 0.370*** | 0.353*** | 0.288** | 0.159 |
| | (0.13) | (0.12) | (0.13) | (0.13) | (0.12) | (0.23) |
| Clouds quantile 3 × I(Post) | 0.181 | 0.168 | 0.168 | 0.183 | 0.147 | 0.219 |
| | (0.13) | (0.12) | (0.13) | (0.13) | (0.13) | (0.23) |
| Clouds quantile 5 × I(Post) | 0.243* | 0.242** | 0.252 | 0.250* | 0.257** | 0.173 |
| | (0.15) | (0.12) | (0.15) | (0.15) | (0.12) | (0.24) |
| Clouds quantile 6 × I(Post) | 0.073 | 0.074 | 0.058 | 0.075 | 0.054 | -0.039 |
| | (0.11) | (0.10) | (0.11) | (0.11) | (0.10) | (0.23) |
| Clouds quantile 7 × I(Post) | 0.261** | 0.221* | 0.285** | 0.258** | 0.244* | 0.311 |
| | (0.13) | (0.13) | (0.13) | (0.13) | (0.13) | (0.23) |
| Clouds quantile 8 × I(Post) | 0.138 | 0.133 | 0.170 | 0.134 | 0.165 | 0.351 |
| | (0.14) | (0.13) | (0.15) | (0.14) | (0.14) | (0.25) |
| FE Year | Y | Y | Y | Y | Y | Y |
| FE Cell | | | | | | Y |
| Wind Controls × I(Post) | | Y | | | Y | Y |
| Abs. Latitude × I(Post) | | | Y | | Y | Y |
| Quarter Controls × I(Post) | | | | Y | Y | Y |
| Clusters | 513 | 513 | 513 | 513 | 513 | 513 |
| Observations | 4,994 | 4,994 | 4,994 | 4,994 | 4,994 | 4,994 |

Note: Table reports OLS estimates. Unit of observation is a grid cell. Coast Sample refers to logbook recordings within 15 kilometres from the coast. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Post is a dummy variable equal to 1 if the logbook recording is dated after 1830. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

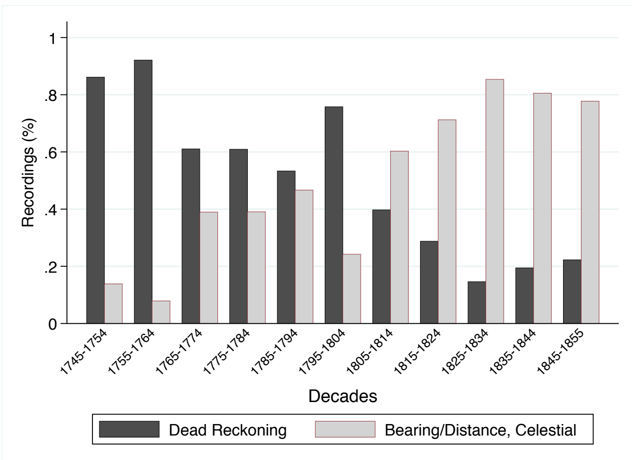
## 2.8 Figures

**Figure 2.1:** Longitude Recordings in CLIWOC: Total Observations




Notes: The unit of observation is a CLIWOC recording. The sample includes recordings using only *Dead Reckoning* or *Bearing/Distance, Celestial*.

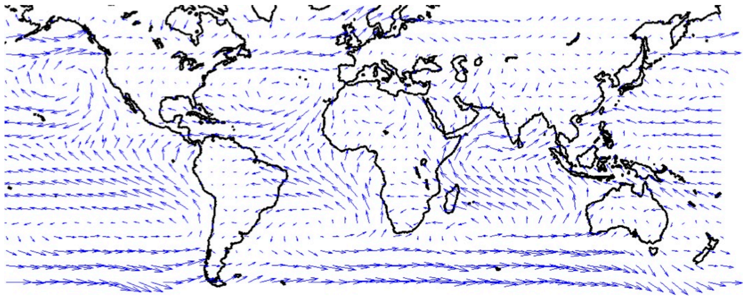
**Figure 2.2:** Longitude Recordings in CLIWOC: Shares



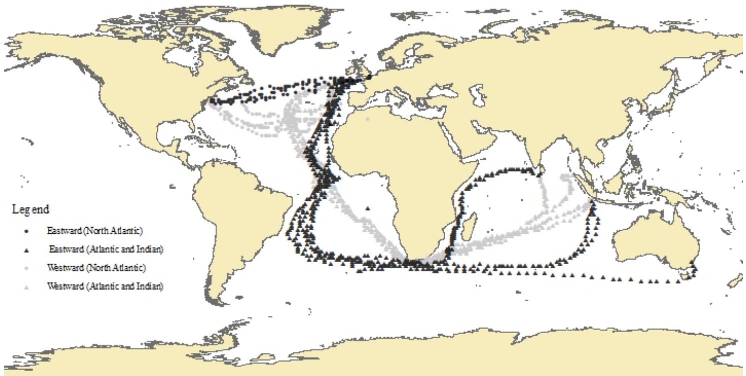

Notes: The unit of observation is a CLIWOC recording. The sample includes recordings using only *Dead Reckoning* or *Bearing/Distance, Celestial*.

**Figure 2.3:** Wind Patterns

**(a)** Current Wind Patterns



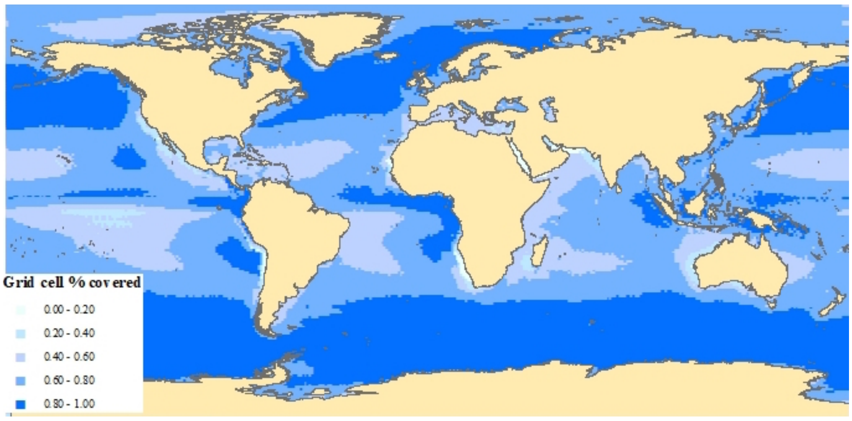
**(b)** Sample of Voyages from CLIWOC



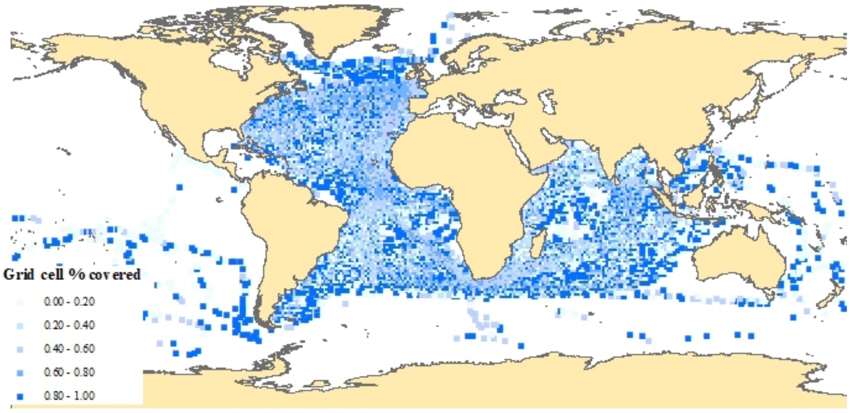

Notes: Panel (a) shows average monthly wind speed and direction. This figure uses data from the months of May (data available from August 1999 to June 2002 at http://woce.nodc.noaa.gov/woce_v3/wocedata_2/sat_mwf/sat_mwf2/). Panel (b) displays journeys from the CLIWOC dataset selected among the North Atlantic route, and the route connecting England to the Indian Ocean. Voyages in black follow a West to East direction, while voyages in grey follow a East to West direction.

**Figure 2.4:** Cloud Coverage Patterns

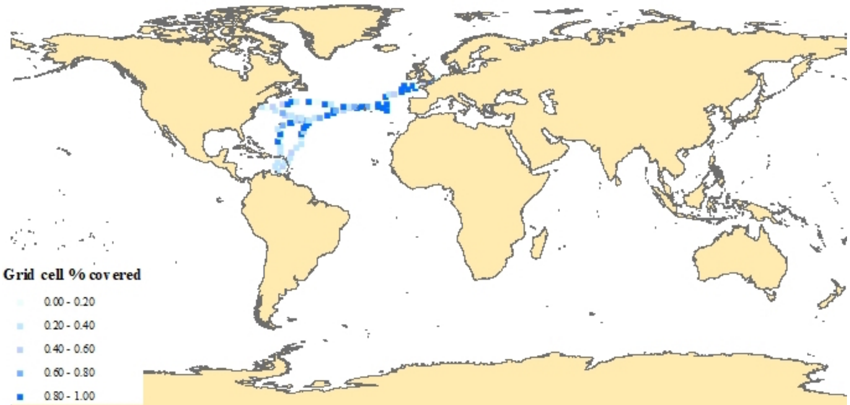
**(a)** Current Cloud Coverage




**(b)** *Clearness*

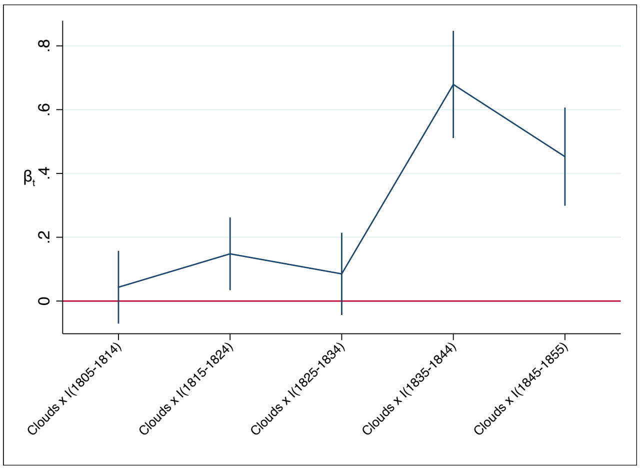



**(c)** *CloudFrac*



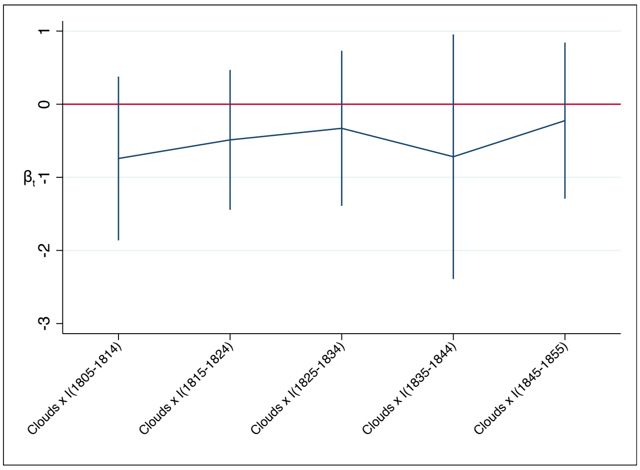

Notes: Panel (a) shows minimum cloud coverage (averaged data available from March 2000 to October 2015 at https://neo.sci.gsfc.nasa.gov). Panel (b) displays the variable *Clearness* from CLIWOC, following the recordings' restriction and conversion as described in the main text. Panel (c) displays the variable *CloudFrac* from CLIWOC, whenever recorded.

**Figure 2.5:** Voyages and Clouds over Time - Open Sea Sample



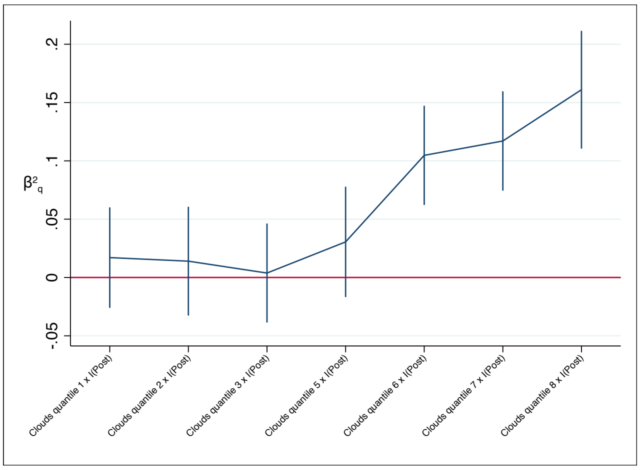

Notes: The figure reports the coefficients from column (5) of Table 2.2. 95 percent confidence intervals shown.

**Figure 2.6:** Voyages and Clouds over Time - Coast Sample



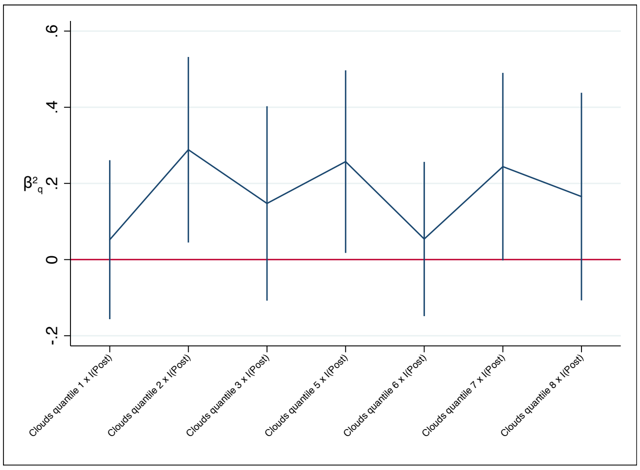

Notes: The figure reports the coefficients from column (5) of Table 2.3. 95 percent confidence intervals shown.

**Figure 2.7:** Speed and Clouds - Open Sea Sample




Notes: The figure reports the coefficients from column (5) of Table 2.4. 95 percent confidence intervals shown.

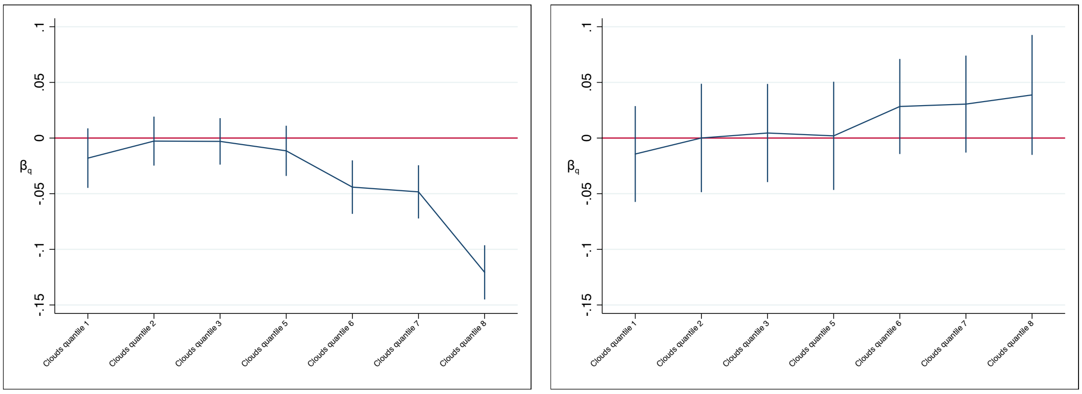
**Figure 2.8:** Speed and Clouds - Coast Sample




Notes: The figure reports the coefficients from column (5) of Table 2.5. 95 percent confidence intervals shown.

**Figure 2.9:** Speed and Clouds, Pre and Post - Open Sea Sample

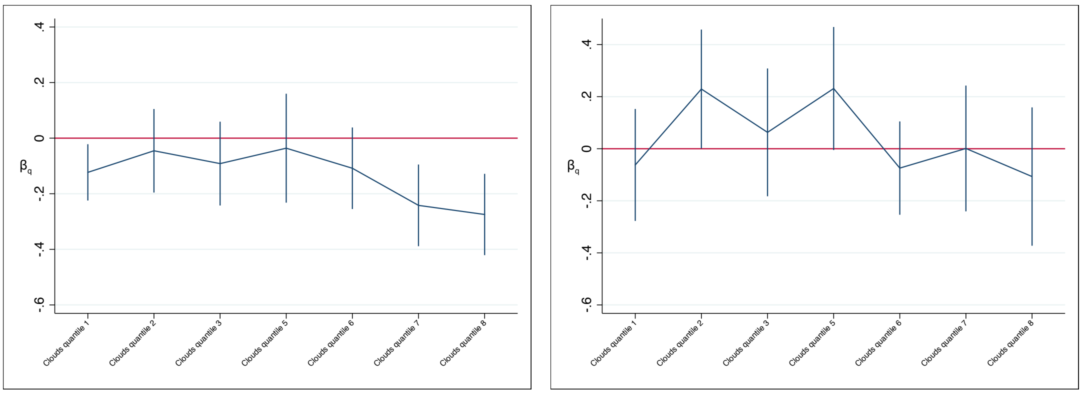
**(a)** Pre Period **(b)** Post Period




Notes: Panel (a) reports the coefficients from column (5) of Table 2.11. Panel (b) reports the coefficients from column (5) of Table 2.12. 95 percent confidence intervals shown.

**Figure 2.10:** Speed and Clouds, Pre and Post - Coast Sample

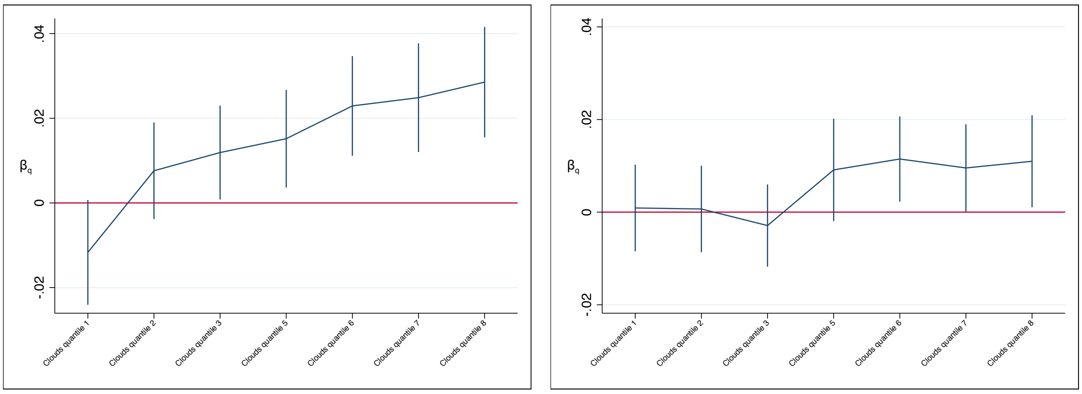
**(a)** Pre Period **(b)** Post Period




Notes: Panel (a) reports the coefficients from column (5) of Table 2.13. Panel (b) reports the coefficients from column (5) of Table 2.14. 95 percent confidence intervals shown.

**Figure 2.11:** Dead Reckoning and Clouds, Pre and Post - Open Sea Sample

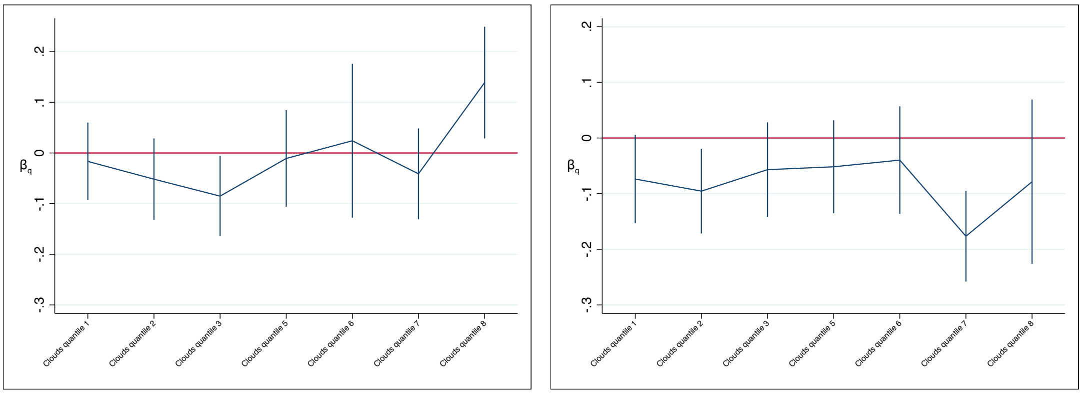
**(a)** Pre Period **(b)** Post Period




Notes: Panels (a) and (b) report the coefficients from regression 2.3 using all controls and fixed effects, in a sample of only open sea navigation. 95 percent confidence intervals shown.

**Figure 2.12:** Dead Reckoning and Clouds, Pre and Post - Coast Sea Sample

**(a)** Pre Period **(b)** Post Period




Notes: Panels (a) and (b) report the coefficients from regression 2.3 using all controls and fixed effects, in a sample of only coastal navigation. 95 percent confidence intervals shown.

## 2.9 Appendix A: Additional Tables

**Table 2.6:** Voyages and Clouds over Time - Open Sea Sample

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Number of travels)* | | |
| Clouds × I(<1750-1754) | 0.348*** | 0.306*** | 0.209** | 0.368*** | 0.218*** |
| | (0.08) | (0.08) | (0.08) | (0.08) | (0.08) |
| Clouds × I(1755-1764) | 0.185** | 0.137* | 0.085 | 0.199*** | 0.088 |
| | (0.07) | (0.07) | (0.08) | (0.07) | (0.08) |
| Clouds × I(1765-1774) | 0.050 | 0.003 | -0.220*** | 0.064 | -0.210** |
| | (0.07) | (0.08) | (0.08) | (0.07) | (0.08) |
| Clouds × I(1775-1784) | 0.116 | 0.067 | -0.191** | 0.126* | -0.179** |
| | (0.07) | (0.08) | (0.08) | (0.07) | (0.08) |
| Clouds × I(1785-1794) | 0.043 | -0.011 | -0.218*** | 0.052 | -0.201*** |
| | (0.07) | (0.07) | (0.07) | (0.07) | (0.07) |
| Clouds × I(1795-1804) | 0.038 | -0.011 | -0.075 | 0.046 | -0.072 |
| | (0.07) | (0.07) | (0.07) | (0.07) | (0.07) |
| Clouds × I(1805-1814) | 0.001 | -0.028 | -0.044 | 0.007 | -0.040 |
| | (0.07) | (0.07) | (0.07) | (0.07) | (0.07) |
| Clouds × I(1815-1824) | 0.104* | 0.064 | 0.068 | 0.113* | 0.074 |
| | (0.06) | (0.06) | (0.06) | (0.06) | (0.06) |
| Clouds × I(1835-1844) | 0.651*** | 0.628*** | 0.583*** | 0.662*** | 0.591*** |
| | (0.07) | (0.07) | (0.08) | (0.07) | (0.08) |
| Clouds × I(1845-1855) | 0.434*** | 0.378*** | 0.355*** | 0.448*** | 0.368*** |
| | (0.07) | (0.07) | (0.07) | (0.07) | (0.07) |
| FE Decade | Y | Y | Y | Y | Y |
| FE Cell | Y | Y | Y | Y | Y |
| Wind Controls × Decade | | Y | | | Y |
| Abs. Latitude × Decade | | | Y | | Y |
| Quarter Controls | | | | Y | Y |
| Clusters | 14,054 | 14,054 | 14,054 | 14,054 | 14,054 |
| Observations | 62,689 | 62,689 | 62,689 | 62,689 | 62,689 |

Note: Table reports OLS estimates. Unit of observation is a grid cell-by-decade. Open Sea Sample refers to logbook recordings at least 15 kilometres away from the coast. The dependent variable is the natural logarithm of 1 plus the number of travels within a grid cell in a decade. Clouds is the fraction of a grid cell covered by clouds, interacted with indicator variables for different decades. The omitted decade is 1825-34. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are percentage of travels in a grid cell by quarter-decade. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.7:** Voyages and Clouds over Time - Coast Sample

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Number of travels)* | | |
| Clouds × I(<1750-1754) | 0.120 | 0.204 | 0.188 | 0.157 | 0.328 |
| | (0.56) | (0.57) | (0.58) | (0.56) | (0.60) |
| Clouds × I(1755-1764) | 0.221 | 0.332 | 0.436 | 0.224 | 0.560 |
| | (0.56) | (0.56) | (0.60) | (0.56) | (0.60) |
| Clouds × I(1765-1774) | 0.236 | 0.421 | 0.310 | 0.238 | 0.506 |
| | (0.79) | (0.77) | (0.78) | (0.78) | (0.76) |
| Clouds × I(1775-1784) | 0.683 | 0.689 | 0.741 | 0.695 | 0.792 |
| | (0.69) | (0.70) | (0.69) | (0.69) | (0.71) |
| Clouds × I(1785-1794) | 0.126 | 0.218 | 0.053 | 0.119 | 0.124 |
| | (0.59) | (0.58) | (0.58) | (0.59) | (0.57) |
| Clouds × I(1795-1804) | -0.091 | 0.108 | -0.004 | -0.077 | 0.196 |
| | (0.61) | (0.58) | (0.62) | (0.60) | (0.60) |
| Clouds × I(1805-1814) | -0.487 | -0.463 | -0.441 | -0.461 | -0.428 |
| | (0.62) | (0.61) | (0.61) | (0.63) | (0.62) |
| Clouds × I(1815-1824) | -0.354 | -0.218 | -0.242 | -0.391 | -0.157 |
| | (0.53) | (0.51) | (0.53) | (0.53) | (0.52) |
| Clouds × I(1835-1844) | -0.459 | -0.490 | -0.382 | -0.435 | -0.374 |
| | (0.60) | (0.60) | (0.61) | (0.60) | (0.62) |
| Clouds × I(1845-1855) | 0.015 | 0.093 | 0.006 | 0.010 | 0.080 |
| | (0.46) | (0.46) | (0.46) | (0.46) | (0.46) |
| FE Decade | Y | Y | Y | Y | Y |
| FE Cell | Y | Y | Y | Y | Y |
| Wind Controls × Decade | | Y | | | Y |
| Abs. Latitude × Decade | | | Y | | Y |
| Quarter Controls | | | | Y | Y |
| Clusters | 560 | 560 | 560 | 560 | 560 |
| Observations | 1,505 | 1,505 | 1,505 | 1,505 | 1,505 |

Note: Table reports OLS estimates. Unit of observation is a grid cell-by-decade. Coast Sample refers to logbook recordings within 15 kilometres from the coast. The dependent variable is the natural logarithm of 1 plus the number of travels within a grid cell in a decade. Clouds is the fraction of a grid cell covered by clouds, interacted with indicator variables for different decades. The omitted decade is 1825-34. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are percentage of travels in a grid cell by quarter-decade. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.8:** Cloud Quantiles

| Quantiles | Min | Max | Cumulated |
|---|---|---|---|
| 1 | 0 | 0.204 | 13.04 |
| 2 | 0.208 | 0.259 | 25.89 |
| 3 | 0.263 | 0.299 | 37.70 |
| 4 | 0.303 | 0.342 | 50.17 |
| 5 | 0.346 | 0.397 | 62.65 |
| 6 | 0.401 | 0.468 | 75.43 |
| 7 | 0.472 | 0.543 | 87.53 |
| 8 | 0.547 | 0.905 | 100.00 |

Note: Unit of observation is a grid cell. Min and Max are lower and upper bounds for cloud coverage quantiles.

**Table 2.9:** Speed and Clouds - Open Sea Sample (Different Standard Errors)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | | |
| Clouds quantile 1 × I(Post) | -0.015 | -0.000 | -0.007 | -0.015 | 0.017 | 0.018 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) |
| | [0.03] | [0.03] | [0.03] | [0.03] | [0.03] | [0.02] |
| Clouds quantile 2 × I(Post) | -0.015 | 0.002 | -0.011 | -0.015 | 0.014 | 0.021 |
| | (0.02) | (0.02) | (0.03) | (0.02) | (0.02) | (0.01) |
| | [0.02] | [0.02] | [0.03] | [0.02] | [0.02] | [0.01] |
| Clouds quantile 3 × I(Post) | 0.003 | 0.004 | 0.003 | 0.002 | 0.004 | -0.001 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) |
| | [0.02] | [0.02] | [0.02] | [0.02] | [0.02] | [0.01] |
| Clouds quantile 5 × I(Post) | 0.007 | 0.032 | 0.004 | 0.007 | 0.031 | 0.016 |
| | (0.03) | (0.02) | (0.03) | (0.03) | (0.02) | (0.01) |
| | [0.03] | [0.02] | [0.03] | [0.03] | [0.02] | [0.01] |
| Clouds quantile 6 × I(Post) | 0.074*** | 0.102*** | 0.072*** | 0.073*** | 0.105*** | 0.042*** |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) |
| | [0.02] | [0.02] | [0.02] | [0.02] | [0.02] | [0.01] |
| Clouds quantile 7 × I(Post) | 0.081*** | 0.127*** | 0.071*** | 0.080*** | 0.117*** | 0.028** |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) |
| | [0.02] | [0.02] | [0.02] | [0.02] | [0.02] | [0.01] |
| Clouds quantile 8 × I(Post) | 0.106*** | 0.160*** | 0.098*** | 0.106*** | 0.161*** | 0.014 |
| | (0.03) | (0.03) | (0.03) | (0.03) | (0.03) | (0.01) |
| | [0.03] | [0.03] | [0.03] | [0.03] | [0.03] | [0.02] |
| FE Year | Y | Y | Y | Y | Y | Y |
| FE Cell | | | | | | Y |
| Wind Controls × I(Post) | | Y | | | Y | Y |
| Abs. Latitude × I(Post) | | | Y | | Y | Y |
| Quarter Controls × I(Post) | | | | Y | Y | Y |
| Observations | 232,561 | 232,561 | 232,561 | 232,561 | 232,561 | 232,561 |

Note: Table reports OLS estimates. Standard errors in ( ) are clustered at the grid cell level; Standard errors in [ ] are two-way clustered at grid cell and ship level. Unit of observation is a grid cell. Open Sea Sample refers to logbook recordings at least 15 kilometres away from the coast. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Post is a dummy variable equal to 1 if the logbook recording is dated after 1830. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.10:** Speed and Clouds - Coast Sample (Different Standard Errors)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | | |
| Clouds quantile 1 × I(Post) | 0.130 | 0.051 | 0.140 | 0.122 | 0.052 | 0.111 |
| | (0.10) | (0.10) | (0.11) | (0.10) | (0.11) | (0.22) |
| | [0.11] | [0.11] | [0.11] | [0.11] | [0.11] | [0.20] |
| Clouds quantile 2 × I(Post) | 0.361*** | 0.287** | 0.370*** | 0.353*** | 0.288** | 0.159 |
| | (0.13) | (0.12) | (0.13) | (0.13) | (0.12) | (0.23) |
| | [0.13] | [0.12] | [0.13] | [0.13] | [0.12] | [0.21] |
| Clouds quantile 3 × I(Post) | 0.181 | 0.168 | 0.168 | 0.183 | 0.147 | 0.219 |
| | (0.13) | (0.12) | (0.13) | (0.13) | (0.13) | (0.23) |
| | [0.12] | [0.12] | [0.13] | [0.12] | [0.13] | [0.23] |
| Clouds quantile 5 × I(Post) | 0.243* | 0.242** | 0.252 | 0.250* | 0.257** | 0.173 |
| | (0.15) | (0.12) | (0.15) | (0.15) | (0.12) | (0.24) |
| | [0.15] | [0.12] | [0.15] | [0.15] | [0.12] | [0.22] |
| Clouds quantile 6 × I(Post) | 0.073 | 0.074 | 0.058 | 0.075 | 0.054 | -0.039 |
| | (0.11) | (0.10) | (0.11) | (0.11) | (0.10) | (0.23) |
| | [0.11] | [0.11] | [0.12] | [0.11] | [0.11] | [0.22] |
| Clouds quantile 7 × I(Post) | 0.261** | 0.221* | 0.285** | 0.258** | 0.244* | 0.311 |
| | (0.13) | (0.13) | (0.13) | (0.13) | (0.13) | (0.23) |
| | [0.12] | [0.12] | [0.12] | [0.12] | [0.12] | [0.22] |
| Clouds quantile 8 × I(Post) | 0.138 | 0.133 | 0.170 | 0.134 | 0.165 | 0.351 |
| | (0.14) | (0.13) | (0.15) | (0.14) | (0.14) | (0.25) |
| | [0.16] | [0.15] | [0.17] | [0.16] | [0.15] | [0.24] |
| FE Year | Y | Y | Y | Y | Y | Y |
| FE Cell | | | | | | Y |
| Wind Controls × I(Post) | | Y | | | Y | Y |
| Abs. Latitude × I(Post) | | | Y | | Y | Y |
| Quarter Controls × I(Post) | | | | Y | Y | Y |
| Observations | 4,994 | 4,994 | 4,994 | 4,994 | 4,994 | 4,994 |

Note: Table reports OLS estimates. Standard errors in ( ) are clustered at the grid cell level; Standard errors in [ ] are two-way clustered at grid cell and ship level. Unit of observation is a grid cell. Coast Sample refers to logbook recordings within 15 kilometres from the coast. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Post is a dummy variable equal to 1 if the logbook recording is dated after 1830. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.11:** Speed and Clouds in the Pre Period - Open Sea Sample

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | |
| Clouds quantile 1 | -0.031** | -0.036*** | -0.021 | -0.031** | -0.018 |
| | (0.01) | (0.01) | (0.02) | (0.01) | (0.01) |
| Clouds quantile 2 | -0.014 | -0.016 | -0.006 | -0.014 | -0.003 |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Clouds quantile 3 | 0.001 | -0.006 | 0.002 | 0.001 | -0.003 |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Clouds quantile 5 | -0.029** | -0.006 | -0.033** | -0.028** | -0.011 |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Clouds quantile 6 | -0.076*** | -0.039*** | -0.082*** | -0.076*** | -0.044*** |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Clouds quantile 7 | -0.087*** | -0.030** | -0.099*** | -0.085*** | -0.048*** |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Clouds quantile 8 | -0.122*** | -0.079*** | -0.143*** | -0.122*** | -0.121*** |
| | (0.02) | (0.01) | (0.02) | (0.02) | (0.01) |
| FE Year | Y | Y | Y | Y | Y |
| Wind Controls | | Y | | | Y |
| Abs. Latitude | | | Y | | Y |
| Quarter Controls | | | | Y | Y |
| Clusters | 12,960 | 12,960 | 12,960 | 12,960 | 12,960 |
| Observations | 171,982 | 171,982 | 171,982 | 171,982 | 171,982 |

Note: Table reports OLS estimates. Unit of observation is a grid cell. Open Sea Sample refers to logbook recordings at least 15 kilometres away from the coast. Pre period are the years before 1830. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.12:** Speed and Clouds in the Post Period - Open Sea Sample

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | |
| Clouds quantile 1 | -0.046* | -0.032 | -0.038 | -0.047* | -0.014 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 2 | -0.029 | -0.012 | -0.025 | -0.029 | 0.000 |
| | (0.03) | (0.02) | (0.03) | (0.03) | (0.02) |
| Clouds quantile 3 | 0.003 | 0.005 | 0.004 | 0.003 | 0.005 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 5 | -0.021 | 0.004 | -0.025 | -0.022 | 0.002 |
| | (0.03) | (0.02) | (0.03) | (0.03) | (0.02) |
| Clouds quantile 6 | -0.002 | 0.026 | -0.004 | -0.003 | 0.028 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 7 | -0.006 | 0.040* | -0.015 | -0.007 | 0.031 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 8 | -0.016 | 0.038 | -0.024 | -0.016 | 0.039 |
| | (0.03) | (0.03) | (0.03) | (0.03) | (0.03) |
| FE Year | Y | Y | Y | Y | Y |
| Wind Controls | | Y | | | Y |
| Abs. Latitude | | | Y | | Y |
| Quarter Controls | | | | Y | Y |
| Clusters | 6,907 | 6,907 | 6,907 | 6,907 | 6,907 |
| Observations | 60,579 | 60,579 | 60,579 | 60,579 | 60,579 |

Note: Table reports OLS estimates. Unit of observation is a grid cell. Open Sea Sample refers to logbook recordings at least 15 kilometres away from the coast. Post period are the years after 1830. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.13:** Speed and Clouds in the Pre Period - Coast Sample

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | |
| Clouds quantile 1 | -0.115* | -0.114** | -0.121** | -0.115* | -0.123** |
| | (0.06) | (0.06) | (0.06) | (0.06) | (0.05) |
| Clouds quantile 2 | -0.059 | -0.040 | -0.063 | -0.061 | -0.045 |
| | (0.09) | (0.08) | (0.08) | (0.09) | (0.08) |
| Clouds quantile 3 | -0.085 | -0.092 | -0.081 | -0.085 | -0.092 |
| | (0.08) | (0.07) | (0.08) | (0.08) | (0.08) |
| Clouds quantile 5 | -0.026 | -0.004 | -0.059 | -0.021 | -0.036 |
| | (0.10) | (0.10) | (0.11) | (0.10) | (0.10) |
| Clouds quantile 6 | -0.128* | -0.115 | -0.120 | -0.130* | -0.108 |
| | (0.08) | (0.08) | (0.08) | (0.07) | (0.07) |
| Clouds quantile 7 | -0.243*** | -0.209** | -0.278*** | -0.236*** | -0.242*** |
| | (0.08) | (0.08) | (0.08) | (0.08) | (0.07) |
| Clouds quantile 8 | -0.272*** | -0.248*** | -0.298*** | -0.268*** | -0.275*** |
| | (0.09) | (0.08) | (0.08) | (0.09) | (0.07) |
| FE Year | Y | Y | Y | Y | Y |
| Wind Controls | | Y | | | Y |
| Abs. Latitude | | | Y | | Y |
| Quarter Controls | | | | Y | Y |
| Clusters | 454 | 454 | 454 | 454 | 454 |
| Observations | 3,138 | 3,138 | 3,138 | 3,138 | 3,138 |

Note: Table reports OLS estimates. Unit of observation is a grid cell. Coast Sample refers to logbook recordings within 15 kilometres from the coast. Pre period are the years before 1830. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.14:** Speed and Clouds in the Post Period - Coast Sample

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | |
| Clouds quantile 1 | 0.015 | -0.064 | 0.025 | 0.008 | -0.062 |
| | (0.11) | (0.11) | (0.12) | (0.11) | (0.11) |
| Clouds quantile 2 | 0.302** | 0.228* | 0.311** | 0.294** | 0.229** |
| | (0.13) | (0.12) | (0.13) | (0.13) | (0.12) |
| Clouds quantile 3 | 0.097 | 0.084 | 0.083 | 0.098 | 0.063 |
| | (0.13) | (0.12) | (0.13) | (0.13) | (0.12) |
| Clouds quantile 5 | 0.217 | 0.216* | 0.227 | 0.224 | 0.231* |
| | (0.17) | (0.12) | (0.17) | (0.17) | (0.12) |
| Clouds quantile 6 | -0.056 | -0.054 | -0.071 | -0.053 | -0.074 |
| | (0.11) | (0.09) | (0.11) | (0.11) | (0.09) |
| Clouds quantile 7 | 0.018 | -0.022 | 0.042 | 0.015 | 0.001 |
| | (0.13) | (0.13) | (0.13) | (0.13) | (0.12) |
| Clouds quantile 8 | -0.134 | -0.139 | -0.103 | -0.139 | -0.107 |
| | (0.14) | (0.13) | (0.15) | (0.14) | (0.13) |
| FE Year | Y | Y | Y | Y | Y |
| Wind Controls | | Y | | | Y |
| Abs. Latitude | | | Y | | Y |
| Quarter Controls | | | | Y | Y |
| Clusters | 194 | 194 | 194 | 194 | 194 |
| Observations | 1,856 | 1,856 | 1,856 | 1,856 | 1,856 |

Note: Table reports OLS estimates. Unit of observation is a grid cell. Post period are the years after 1830. Coast Sample refers to logbook recordings within 15 kilometres from the coast. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.15:** Speed and Clouds - Open Sea Sample (Ship Fixed Effects)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | | |
| Clouds quantile 1 × I(Post) | -0.031 | -0.021 | -0.024 | -0.031 | -0.004 | 0.014 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) |
| | [0.03] | [0.02] | [0.03] | [0.03] | [0.02] | [0.02] |
| Clouds quantile 2 × I(Post) | -0.016 | -0.001 | -0.012 | -0.016 | 0.011 | 0.022* |
| | (0.02) | (0.02) | (0.03) | (0.02) | (0.02) | (0.01) |
| | [0.02] | [0.02] | [0.03] | [0.02] | [0.02] | [0.01] |
| Clouds quantile 3 × I(Post) | 0.011 | 0.010 | 0.012 | 0.011 | 0.010 | 0.003 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) |
| | [0.02] | [0.02] | [0.02] | [0.02] | [0.02] | [0.01] |
| Clouds quantile 5 × I(Post) | 0.006 | 0.031 | 0.003 | 0.005 | 0.029 | 0.015 |
| | (0.03) | (0.02) | (0.03) | (0.03) | (0.02) | (0.01) |
| | [0.03] | [0.02] | [0.03] | [0.03] | [0.02] | [0.01] |
| Clouds quantile 6 × I(Post) | 0.062*** | 0.090*** | 0.061*** | 0.061*** | 0.093*** | 0.040*** |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) |
| | [0.02] | [0.02] | [0.02] | [0.02] | [0.02] | [0.01] |
| Clouds quantile 7 × I(Post) | 0.071*** | 0.118*** | 0.062*** | 0.070*** | 0.108*** | 0.029** |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.01) |
| | [0.02] | [0.02] | [0.02] | [0.02] | [0.02] | [0.01] |
| Clouds quantile 8 × I(Post) | 0.091*** | 0.147*** | 0.084*** | 0.091*** | 0.150*** | 0.016 |
| | (0.02) | (0.03) | (0.03) | (0.02) | (0.03) | (0.01) |
| | [0.03] | [0.03] | [0.03] | [0.03] | [0.03] | [0.02] |
| FE Year | Y | Y | Y | Y | Y | Y |
| FE Ship | Y | Y | Y | Y | Y | Y |
| FE Cell | | | | | | Y |
| Wind Controls × I(Post) | | Y | | | Y | Y |
| Abs. Latitude × I(Post) | | | Y | | Y | Y |
| Quarter Controls × I(Post) | | | | Y | Y | Y |
| Observations | 232,561 | 232,561 | 232,561 | 232,561 | 232,561 | 232,561 |

Note: Table reports OLS estimates. Standard errors in ( ) are clustered at the grid cell level; Standard errors in [ ] are two-way clustered at grid cell and ship level. Unit of observation is a grid cell. Open Sea Sample refers to logbook recordings at least 15 kilometres away from the coast. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Post is a dummy variable equal to 1 if the logbook recording is dated after 1830. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.16:** Speed and Clouds - Coast Sample (Ship Fixed Effects)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | | |
| Clouds quantile 1 × I(Post) | 0.084 | 0.002 | 0.092 | 0.079 | 0.008 | 0.189 |
| | (0.11) | (0.12) | (0.12) | (0.11) | (0.13) | (0.23) |
| | [0.12] | [0.13] | [0.12] | [0.12] | [0.13] | [0.23] |
| Clouds quantile 2 × I(Post) | 0.338*** | 0.262** | 0.346*** | 0.333*** | 0.267** | 0.236 |
| | (0.13) | (0.13) | (0.13) | (0.13) | (0.13) | (0.24) |
| | [0.13] | [0.13] | [0.14] | [0.13] | [0.13] | [0.23] |
| Clouds quantile 3 × I(Post) | 0.151 | 0.139 | 0.142 | 0.154 | 0.123 | 0.263 |
| | (0.12) | (0.12) | (0.13) | (0.13) | (0.14) | (0.26) |
| | [0.13] | [0.13] | [0.13] | [0.13] | [0.14] | [0.28] |
| Clouds quantile 5 × I(Post) | 0.232 | 0.230** | 0.239 | 0.239 | 0.247** | 0.283 |
| | (0.15) | (0.12) | (0.15) | (0.15) | (0.12) | (0.25) |
| | [0.14] | [0.12] | [0.15] | [0.14] | [0.12] | [0.25] |
| Clouds quantile 6 × I(Post) | 0.023 | 0.022 | 0.014 | 0.023 | 0.005 | -0.037 |
| | (0.12) | (0.12) | (0.12) | (0.12) | (0.12) | (0.26) |
| | [0.13] | [0.13] | [0.13] | [0.13] | [0.13] | [0.27] |
| Clouds quantile 7 × I(Post) | 0.211 | 0.168 | 0.227* | 0.204 | 0.188 | 0.399 |
| | (0.13) | (0.14) | (0.13) | (0.13) | (0.14) | (0.25) |
| | [0.12] | [0.13] | [0.13] | [0.12] | [0.13] | [0.26] |
| Clouds quantile 8 × I(Post) | 0.111 | 0.098 | 0.130 | 0.107 | 0.125 | 0.385 |
| | (0.14) | (0.14) | (0.15) | (0.14) | (0.15) | (0.25) |
| | [0.19] | [0.19] | [0.20] | [0.19] | [0.19] | [0.26] |
| FE Year | Y | Y | Y | Y | Y | Y |
| FE Ship | Y | Y | Y | Y | Y | Y |
| FE Cell | | | | | | Y |
| Wind Controls × I(Post) | | Y | | | Y | Y |
| Abs. Latitude × I(Post) | | | Y | | Y | Y |
| Quarter Controls × I(Post) | | | | Y | Y | Y |
| Observations | 4,994 | 4,994 | 4,994 | 4,994 | 4,994 | 4,994 |

Note: Table reports OLS estimates. Standard errors in ( ) are clustered at the grid cell level; Standard errors in [ ] are two-way clustered at grid cell and ship level. Unit of observation is a grid cell. Coast Sample refers to logbook recordings within 15 kilometres from the coast. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Post is a dummy variable equal to 1 if the logbook recording is dated after 1830. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.17:** Speed and Clouds in the Pre Period - Open Sea Sample (Ship Fixed Effects)

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | |
| Clouds quantile 1 | -0.003 | -0.013 | 0.007 | -0.003 | 0.002 |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Clouds quantile 2 | -0.008 | -0.012 | -0.000 | -0.008 | 0.001 |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Clouds quantile 3 | 0.001 | -0.005 | 0.003 | 0.001 | -0.002 |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Clouds quantile 5 | -0.028** | -0.008 | -0.033*** | -0.028** | -0.015 |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Clouds quantile 6 | -0.070*** | -0.039*** | -0.075*** | -0.069*** | -0.044*** |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Clouds quantile 7 | -0.083*** | -0.034*** | -0.096*** | -0.082*** | -0.052*** |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Clouds quantile 8 | -0.110*** | -0.074*** | -0.125*** | -0.110*** | -0.100*** |
| | (0.02) | (0.01) | (0.02) | (0.02) | (0.01) |
| FE Year | Y | Y | Y | Y | Y |
| FE Ship | Y | Y | Y | Y | Y |
| Wind Controls | | Y | | | Y |
| Abs. Latitude | | | Y | | Y |
| Quarter Controls | | | | Y | Y |
| Clusters | 12,960 | 12,960 | 12,960 | 12,960 | 12,960 |
| Observations | 171,982 | 171,982 | 171,982 | 171,982 | 171,982 |

Note: Table reports OLS estimates. Unit of observation is a grid cell. Open Sea Sample refers to logbook recordings at least 15 kilometres away from the coast. Pre period are the years before 1830. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.18:** Speed and Clouds in the Post Period - Open Sea Sample (Ship Fixed Effects)

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | |
| Clouds quantile 1 | -0.034 | -0.024 | -0.027 | -0.034 | -0.007 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 2 | -0.024 | -0.010 | -0.021 | -0.024 | 0.003 |
| | (0.03) | (0.02) | (0.03) | (0.03) | (0.02) |
| Clouds quantile 3 | 0.014 | 0.012 | 0.014 | 0.013 | 0.013 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 5 | -0.023 | 0.003 | -0.026 | -0.023 | 0.001 |
| | (0.03) | (0.02) | (0.03) | (0.03) | (0.02) |
| Clouds quantile 6 | -0.009 | 0.019 | -0.011 | -0.010 | 0.021 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 7 | -0.014 | 0.034 | -0.022 | -0.014 | 0.024 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 8 | -0.021 | 0.036 | -0.028 | -0.022 | 0.038 |
| | (0.03) | (0.03) | (0.03) | (0.03) | (0.03) |
| FE Year | Y | Y | Y | Y | Y |
| FE Ship | Y | Y | Y | Y | Y |
| Wind Controls | | Y | | | Y |
| Abs. Latitude | | | Y | | Y |
| Quarter Controls | | | | Y | Y |
| Clusters | 6,907 | 6,907 | 6,907 | 6,907 | 6,907 |
| Observations | 60,579 | 60,579 | 60,579 | 60,579 | 60,579 |

Note: Table reports OLS estimates. Unit of observation is a grid cell. Open Sea Sample refers to logbook recordings at least 15 kilometres away from the coast. Post period are the years after 1830. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.19:** Speed and Clouds in the Pre Period - Coast Sample (Ship Fixed Effects)

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | |
| Clouds quantile 1 | -0.084 | -0.096 | -0.086 | -0.081 | -0.096 |
| | (0.07) | (0.07) | (0.07) | (0.07) | (0.07) |
| Clouds quantile 2 | -0.052 | -0.041 | -0.053 | -0.049 | -0.039 |
| | (0.09) | (0.09) | (0.09) | (0.09) | (0.08) |
| Clouds quantile 3 | -0.056 | -0.076 | -0.054 | -0.054 | -0.073 |
| | (0.08) | (0.08) | (0.08) | (0.09) | (0.08) |
| Clouds quantile 5 | -0.039 | -0.026 | -0.060 | -0.030 | -0.042 |
| | (0.09) | (0.08) | (0.10) | (0.09) | (0.09) |
| Clouds quantile 6 | -0.098 | -0.097 | -0.094 | -0.095 | -0.088 |
| | (0.09) | (0.09) | (0.09) | (0.09) | (0.09) |
| Clouds quantile 7 | -0.207** | -0.182** | -0.226** | -0.193** | -0.191** |
| | (0.09) | (0.09) | (0.09) | (0.09) | (0.09) |
| Clouds quantile 8 | -0.256*** | -0.253*** | -0.264*** | -0.253*** | -0.260*** |
| | (0.10) | (0.09) | (0.09) | (0.10) | (0.09) |
| FE Year | Y | Y | Y | Y | Y |
| FE Ship | Y | Y | Y | Y | Y |
| Wind Controls | | Y | | | Y |
| Abs. Latitude | | | Y | | Y |
| Quarter Controls | | | | Y | Y |
| Clusters | 454 | 454 | 454 | 454 | 454 |
| Observations | 3,138 | 3,138 | 3,138 | 3,138 | 3,138 |

Note: Table reports OLS estimates. Unit of observation is a grid cell. Coast Sample refers to logbook recordings within 15 kilometres from the coast. Pre period are the years before 1830. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.20:** Speed and Clouds in the Post Period - Coast Sample (Ship Fixed Effects)

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Dependent variable:* | | | *ln(1+Ship speed)* | | |
| Clouds quantile 1 | -0.005 | -0.086 | 0.002 | -0.011 | -0.083 |
| | (0.11) | (0.11) | (0.11) | (0.11) | (0.12) |
| Clouds quantile 2 | 0.286** | 0.209* | 0.292** | 0.280** | 0.212* |
| | (0.12) | (0.11) | (0.12) | (0.12) | (0.12) |
| Clouds quantile 3 | 0.079 | 0.070 | 0.072 | 0.082 | 0.055 |
| | (0.11) | (0.11) | (0.12) | (0.11) | (0.12) |
| Clouds quantile 5 | 0.174 | 0.173 | 0.179 | 0.180 | 0.186* |
| | (0.15) | (0.11) | (0.15) | (0.15) | (0.11) |
| Clouds quantile 6 | -0.096 | -0.095 | -0.102 | -0.095 | -0.109 |
| | (0.09) | (0.09) | (0.09) | (0.09) | (0.09) |
| Clouds quantile 7 | 0.001 | -0.042 | 0.013 | -0.007 | -0.027 |
| | (0.12) | (0.14) | (0.13) | (0.13) | (0.14) |
| Clouds quantile 8 | -0.146 | -0.159 | -0.132 | -0.150 | -0.138 |
| | (0.12) | (0.12) | (0.13) | (0.13) | (0.13) |
| FE Year | Y | Y | Y | Y | Y |
| FE Ship | Y | Y | Y | Y | Y |
| Wind Controls | | Y | | | Y |
| Abs. Latitude | | | Y | | Y |
| Quarter Controls | | | | Y | Y |
| Clusters | 194 | 194 | 194 | 194 | 194 |
| Observations | 1,856 | 1,856 | 1,856 | 1,856 | 1,856 |

Note: Table reports OLS estimates. Unit of observation is a grid cell. Coast Sample refers to logbook recordings within 15 kilometres from the coast. Post period are the years after 1830. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.21:** Voyages and Clouds over Time - Open Sea Sample (Different Definition of Coast)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| *Coast Definition:* | *5 km* | *10 km* | *15 km* | *20 km* | *30 km* | *50 km* |
| Clouds × I(1805-1814) | 0.043 | 0.042 | 0.043 | 0.043 | 0.034 | 0.036 |
| | (0.06) | (0.06) | (0.06) | (0.06) | (0.06) | (0.06) |
| Clouds × I(1815-1824) | 0.149** | 0.148** | 0.148** | 0.143** | 0.139** | 0.145** |
| | (0.06) | (0.06) | (0.06) | (0.06) | (0.06) | (0.06) |
| Clouds × I(1825-1834) | 0.076 | 0.076 | 0.085 | 0.088 | 0.091 | 0.116* |
| | (0.07) | (0.07) | (0.07) | (0.07) | (0.07) | (0.07) |
| Clouds × I(1835-1844) | 0.685*** | 0.685*** | 0.679*** | 0.683*** | 0.691*** | 0.717*** |
| | (0.09) | (0.09) | (0.09) | (0.09) | (0.09) | (0.09) |
| Clouds × I(1845-1855) | 0.451*** | 0.452*** | 0.453*** | 0.452*** | 0.455*** | 0.460*** |
| | (0.08) | (0.08) | (0.08) | (0.08) | (0.08) | (0.08) |
| FE Decade | Y | Y | Y | Y | Y | Y |
| FE Grid cell | Y | Y | Y | Y | Y | Y |
| Wind Controls × Decade | Y | Y | Y | Y | Y | Y |
| Abs. Latitude × Decade | Y | Y | Y | Y | Y | Y |
| Quarter Controls | Y | Y | Y | Y | Y | Y |
| Clusters | 14,215 | 14,143 | 14,054 | 13,990 | 13,826 | 13,498 |
| Observations | 63,113 | 62,942 | 62,689 | 62,429 | 61,864 | 60,850 |

Note: Table reports OLS estimates. Unit of observation is a grid cell-by-decade. Open Sea Sample refers to logbook recordings at least 5, 10, 15, 20, 30, 50 kilometres away from the coast, in columns 1-6, respectively. The dependent variable is the natural logarithm of 1 plus the number of travels within a grid cell in a decade. Clouds is the fraction of a grid cell covered by clouds, interacted with indicator variables for different decades. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are percentage of travels in a grid cell by quarter-decade. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.22:** Voyages and Clouds over Time - Coast Sample (Different Definition of Coast)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| *Coast Definition:* | *5 km* | *10 km* | *15 km* | *20 km* | *30 km* | *50 km* |
| Clouds × I(1805-1814) | -0.825 | -0.699 | -0.742 | -0.705 | -0.070 | -0.017 |
| | (0.67) | (0.61) | (0.57) | (0.51) | (0.41) | (0.33) |
| Clouds × I(1815-1824) | -0.670 | -0.625 | -0.488 | -0.408 | -0.188 | -0.149 |
| | (0.56) | (0.53) | (0.49) | (0.44) | (0.41) | (0.35) |
| Clouds × I(1825-1834) | -0.465 | -0.355 | -0.330 | -0.390 | -0.122 | -0.238 |
| | (0.68) | (0.64) | (0.54) | (0.48) | (0.45) | (0.38) |
| Clouds × I(1835-1844) | -1.279 | -0.996 | -0.718 | -0.664 | -0.498 | -0.581 |
| | (0.98) | (0.91) | (0.85) | (0.72) | (0.70) | (0.54) |
| Clouds × I(1845-1855) | -0.341 | -0.187 | -0.225 | -0.155 | -0.000 | 0.012 |
| | (0.68) | (0.65) | (0.54) | (0.50) | (0.52) | (0.46) |
| FE Decade | Y | Y | Y | Y | Y | Y |
| FE Grid cell | Y | Y | Y | Y | Y | Y |
| Wind Controls × Decade | Y | Y | Y | Y | Y | Y |
| Abs. Latitude × Decade | Y | Y | Y | Y | Y | Y |
| Quarter Controls | Y | Y | Y | Y | Y | Y |
| Clusters | 399 | 471 | 560 | 624 | 788 | 1116 |
| Observations | 1,084 | 1,254 | 1,505 | 1,756 | 2,318 | 3,328 |

Note: Table reports OLS estimates. Unit of observation is a grid cell-by-decade. Coast Sample refers to logbook recordings within 5, 10, 15, 20, 30, 50 kilometres from the coast, in columns 1-6, respectively. The dependent variable is the natural logarithm of 1 plus the number of travels within a grid cell in a decade. Clouds is the fraction of a grid cell covered by clouds, interacted with indicator variables for different decades. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are percentage of travels in a grid cell by quarter-decade. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.23:** Speed and Clouds - Open Sea Sample (Different Definition of Coast)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| *Coast Definition:* | *5 km* | *10 km* | *15 km* | *20 km* | *30 km* | *50 km* |
| Clouds quantile 1 × I(Post) | 0.019 | 0.016 | 0.017 | 0.021 | 0.021 | 0.026 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 2 × I(Post) | 0.018 | 0.014 | 0.014 | 0.025 | 0.024 | 0.021 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 3 × I(Post) | 0.007 | 0.004 | 0.004 | 0.007 | 0.005 | -0.007 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 5 × I(Post) | 0.027 | 0.023 | 0.031 | 0.031 | 0.038 | 0.040** |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 6 × I(Post) | 0.109*** | 0.105*** | 0.105*** | 0.105*** | 0.099*** | 0.082*** |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 7 × I(Post) | 0.120*** | 0.117*** | 0.117*** | 0.118*** | 0.115*** | 0.094*** |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) | (0.02) |
| Clouds quantile 8 × I(Post) | 0.166*** | 0.162*** | 0.161*** | 0.160*** | 0.166*** | 0.138*** |
| | (0.03) | (0.03) | (0.03) | (0.03) | (0.02) | (0.02) |
| Year FE | Y | Y | Y | Y | Y | Y |
| Wind Controls × I(Post) | Y | Y | Y | Y | Y | Y |
| Abs. Latitude × I(Post) | Y | Y | Y | Y | Y | Y |
| Quarter Controls × I(Post) | Y | Y | Y | Y | Y | Y |
| Clusters | 13,863 | 13,802 | 13,722 | 13,662 | 13,507 | 13,190 |
| Observations | 233,825 | 233,350 | 232,561 | 231,136 | 228,539 | 224,504 |

Note: Table reports OLS estimates. Unit of observation is a grid cell. Open Sea Sample refers to logbook recordings at least 5, 10, 15, 20, 30, 50 kilometres away from the coast, in columns 1-6, respectively. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Post is a dummy variable equal to 1 if the logbook recording is dated after 1830. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

**Table 2.24:** Speed and Clouds - Coast Sample (Different Definition of Coast)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| *Coast Definition:* | *5 km* | *10 km* | *15 km* | *20 km* | *30 km* | *50 km* |
| Clouds quantile 1 × I(Post) | 0.065 | 0.107 | 0.052 | -0.067 | -0.013 | 0.103 |
| | (0.18) | (0.11) | (0.11) | (0.10) | (0.08) | (0.07) |
| Clouds quantile 2 × I(Post) | 0.274 | 0.327*** | 0.288** | -0.003 | 0.035 | 0.121 |
| | (0.18) | (0.10) | (0.12) | (0.13) | (0.11) | (0.09) |
| Clouds quantile 3 × I(Post) | 0.140 | 0.181 | 0.147 | -0.023 | 0.020 | 0.106 |
| | (0.21) | (0.14) | (0.13) | (0.12) | (0.10) | (0.10) |
| Clouds quantile 5 × I(Post) | 0.380** | 0.572*** | 0.257** | 0.121 | 0.084 | 0.137 |
| | (0.19) | (0.11) | (0.12) | (0.13) | (0.10) | (0.09) |
| Clouds quantile 6 × I(Post) | -0.033 | 0.116 | 0.054 | -0.047 | 0.072 | 0.196* |
| | (0.19) | (0.11) | (0.10) | (0.12) | (0.10) | (0.10) |
| Clouds quantile 7 × I(Post) | 0.270 | 0.360*** | 0.244* | 0.069 | 0.091 | 0.196** |
| | (0.19) | (0.13) | (0.13) | (0.13) | (0.09) | (0.08) |
| Clouds quantile 8 × I(Post) | 0.144 | 0.158 | 0.165 | 0.008 | -0.019 | 0.368** |
| | (0.21) | (0.14) | (0.14) | (0.14) | (0.10) | (0.16) |
| Year FE | Y | Y | Y | Y | Y | Y |
| Wind Controls × I(Post) | Y | Y | Y | Y | Y | Y |
| Abs. Latitude × I(Post) | Y | Y | Y | Y | Y | Y |
| Quarter Controls × I(Post) | Y | Y | Y | Y | Y | Y |
| Clusters | 371 | 432 | 513 | 575 | 732 | 1,050 |
| Observations | 3,730 | 4,205 | 4,994 | 6,419 | 9,016 | 13,051 |

Note: Table reports OLS estimates. Unit of observation is a grid cell. Coast Sample refers to logbook recordings within 5, 10, 15, 20, 30, 50 kilometres from the coast, in columns 1-6, respectively. The dependent variable is the natural logarithm of 1 plus the speed of a ship (km/h). Clouds quantiles are dummy variables equal to 1 assigned to grid cells within a cloud coverage as reported in Table 2.8 of Appendix A. Post is a dummy variable equal to 1 if the logbook recording is dated after 1830. Wind Controls are average wind force and average wind direction; Abs. Latitude is the absolute level of latitude; Quarter Controls are dummy variables for a logbook recording's quarter. Standard errors clustered at the grid cell level in parentheses. *, ** and *** indicate significance at the 10, 5 and 1 percent levels, respectively.

# Chapter 3

# Menstrual Health, Worker Productivity and Well-being among Female Bangladeshi Garment Workers

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## 3.1 Introduction

The importance of menstrual health in affecting the work, well-being, earning capabilities and other aspects of women's lives in poor countries has recently been recognised in development economics. While the evidence on whether women's work lives in richer countries are affected by the menstrual cycle is inconclusive (Ichino and Moretti (2009); Sullivan (2011); Herrmann and Rockoff (2012, 2013)), there are many reasons to believe that poorer women in developing countries are affected more strongly. They often lack access to hygiene products to manage their period, resulting in potentially severe health risks (Ahmed and Yesmin (2008); Sumpter and Torondel (2013); Hulland et al. (2015); Garikipati and Boudot (2017); Kaur et al. (2018)). These women are also subject to widespread taboos and stigmatisation of menstruation, hindering their access to information and products for adequate menstrual health management (Ali and Rizvi (2010); McMahon et al. (2011); Crichton et al. (2013); Mason et al. (2013)).

The literature on menstrual health and development so far has had a strong focus on whether adolescent girls drop out of school when they reach menarche, limiting human capital accumulation (El-Gilany et al. (2005); Oster and Thornton (2011); Montgomery et al. (2012, 2016); Alam et al. (2017); Girod et al. (2017); van Eijk et al. (2017); Benshaul-Tolonen et al. (2019); Khanna (2019)). The severity of this problem seems to vary substantially across countries, though broadly improving over time.

Less is known about how limited access to menstrual health products affects working women in poor countries. This question is important because absenteeism or low productivity could translate more imminently into earnings on the job. Furthermore, secondary schooling rates are still low in many developing countries, particularly among girls.[3] Nevertheless, many of the girls missing out on education still participate in the labour force later on, as they are often from the poorest segments of society. Thus, working women constitute a different population than adolescent school girls for research on menstruation, productivity, health and well-being.[4]

[3] For example, secondary schooling rates for girls are 73 percent in Bangladesh in 2017, and only 38 percent among all low income countries across the world in 2017 (data.worldbank.org).

[4] An exception to the general scarcity of research on the link between menstrual health and work life in developing countries are Krenz and Strulik (2019), who find that in Burkina Faso, access to sanitary pads reduces work absenteeism by around 20 percent, using propensity score matching. Sommer et al. (2016) make the case for more research in this area from a broader policy perspective. Also, Garikipati and Boudot (2017) stress that the most vulnerable populations in developing countries to lack access to good menstrual health products may not be schoolgirls anymore but rather marginalised communities beyond school age, particularly in the South Asian context.

We present the results from a randomised trial in which poor working women in Bangladesh are provided with either free hygienic menstrual health products (disposable sanitary pads), information on the importance of hygienic menstrual health management (henceforth MHM) for their overall health and well-being, or both. This trial mirrors randomised trials that provide free MHM products to school girls (Oster and Thornton (2011); Montgomery et al. (2012, 2016); Benshaul-Tolonen et al. (2019)), but is, to the best of our knowledge, the first that targets working women.[5] More specifically, the trial is conducted at three large export-oriented garment factories in Bangladesh, which provide an ideal setting for this study as these factories predominantly employ female migrant workers, who earn around 80-160USD per month for full time work. The Bangladeshi garment sector is the second largest in the world, employing more than four million workers over more than 4,000 factories, while paying among the lowest wages among the garment export sectors in the world (ILO (2014)). Nevertheless, the opportunity for women, even without formal skills, to find work in the sector has been credited with marked improvements in their socio-economic position in the country (Heath and Mobarak (2015)), similar to what has been shown for other export manufacturing sectors in developing countries around the world (Atkin (2017); Getahun and Villanger (2018); Tanaka (forthcoming)).

In our sample, 41 percent of women report using disposable sanitary pads regularly at baseline, while another 9 percent report using them occasionally, with the remainder using "traditional" MHM remedies such as old cloth, rags, or tissue paper. The randomised trial is designed to relax independently the main potential constraints to widespread adoption of sanitary pads by the workers. After extensive discussions with relevant NGOs and experts in our setting, we identified three main constraints: financial burden, lack of information and stigmatisation.[6] First, we relax financial constraints through the provision of free sanitary pads at the workplace. Second, we relax information constraints through information and awareness sessions implemented by an experienced NGO that has conducted such sessions for many years in garment factories in Bangladesh. Third, we relax stigma-related constraints, which we address through variations in each of the two main treatments

[5]It also differs from the first two trials as they provided menstrual cups and reusable pads, respectively, while our trial provided disposable sanitary pads. Benshaul-Tolonen et al. (2019) provide both sanitary pads and menstrual cups in different treatment arms. However, in our study we focused on providing the most commonly known "modern" menstrual product in our setting, disposable sanitary pads, to maximise take-up, and did not attempt to compare the effectiveness of different MHM products.

[6]These experts are based at BRAC University, the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B), Business for Social Responsibility™ HERProject, SNV Netherlands Development Organisation, and Phulki.

arms. In the free-pads treatment arm we vary exogenously whether the pads can be collected from a male or female distribution worker. This mirrors the widespread concern in the country that women do not like to buy pads in the shops that sell them, because they are predominantly staffed by men. Meanwhile, in the information sessions, we randomly vary their information content. While half of the sessions focus on the message that using hygienic MHM products improves workers' health, the other half has an additional module stressing that sanitary pads have a better absorbing capacity than traditional materials used during the menstrual cycle, such as cloth. Therefore, they reduce the risk of "embarrassing" leakage which would reveal that a worker has her period to others, a main concern reported by workers during preliminary work in our setting.[7] Thus, we can test whether a stigma-reduction message has a different effect on worker's MHM compared to a health-improvement message.

We find that, half a year after the information sessions and availability of free pads in the time in between, the workers with access to free pads are 10 percentage points more likely to report using pads, regardless of whether they also attend the information session. The workers who only attend the information session but did not have access to free pads are 6-7 percentage points more likely to report using pads. Among workers who report not using pads at baseline and are still at the factory for the follow-up survey, the effects are 22 and 13 percentage points, respectively. Regarding further downstream outcomes, we find that workers who have only access to free pads, or who have only attended the information session, have 15 percent and 25 percent fewer absent days at work, respectively. However, we do not find such an effect among workers who both have access to free pads and attend the information sessions. We also do not find statistically significant effects on earnings, overtime hours, worker turnover, or on self-reported well-being at work. We find that workers who have access to free pads have a higher willingness to pay for pads at follow-up (elicited through the incentivised Becker-DeGroot-Marschak mechanism), but those who have both the access to free pads and attend the information session do not.

Whether the information sessions contain the "stigma" module or not does not make a difference for either the self-reported use of pads or further downstream results, and, perhaps surprisingly, workers collect free pads from the male distribution worker at the same rate as from the female distribution worker. This suggests that these stigma-related constraints are not binding in this setting, at least in the

[7] The fear of revealing one's menstrual status to others, particularly to males, is also widely reported in studies on MHM among school girls, e.g. in WaterAid (2009).

particular way we relax them. However, in the follow-up survey we find that workers who attend the information sessions (with or without the stigma module) are less likely to agree with a number of common taboos surrounding menstruation in Bangladesh. For example, they report to adhere less to the taboo on drying the cloth used during the period outside in the sun after washing it. These effects show up both in response to questions on personal behaviours as well as on perceived social norms regarding such behaviours. The questions on social norms are incentivised for truthful revelation of these norms, to minimise desirability bias in answers.

Thus, increased awareness about good MHM practice and availability of free pads increase self-reported pad use, may reduce work absenteeism, and increase the valuation of pads. Furthermore, the information sessions, at a minimum, increase awareness about the harmfulness of traditional taboos surrounding menstruation. For example, the common taboo to not dry one's menstrual cloth outside in the sun after washing it is harmful because drying the cloth inside (usually within cupboards to be hidden even from the view of family members) keeps it damp, and susceptible to fungus. Furthermore, UV light would disinfect the cloth, making its use more hygienic (Ahmed and Yesmin (2008)). We caution the reader that this trial has so far been run on a sample of 1,000 workers, and a second iteration of the trial with more than 1,000 additional workers from a different factory is planned to start in September 2019. Only with these workers added to the sample will we have reached the targeted sample size and statistical power of this study. We are planning to keep collecting administrative data from the Human Resource (HR) departments of the first three factories on absenteeism, turnover, overtime, and earnings. Thus, for these important outcome variables, our dataset will not only increase in the cross-section, but also along its longitudinal dimension.

The Bangladeshi garment export sector is an interesting and relevant setting to study the effects of workplace MHM interventions on worker outcomes and well-being, not only due to the millions of jobs it creates for poor migrant workers, who otherwise can typically only access informal, casual or family based employment. Even more, export manufacturing sectors across the world, while being credited with generating growth and poverty reduction (Harrison (2007); Berg et al. (2012); Haraguchi et al. (2017)), often struggle with high worker absenteeism and turnover rates. For example, Blattmann and Dercon (2018) find 77 percent annual turnover for factory jobs in Ethiopia, while for the Bangladeshi garment export sector, Menzel and Woodruff (2019) find daily absenteeism rates of 3-4 percent and monthly worker turnover rates of 5 percent.[8] Given the large number of female workers that export manufacturing employs around the world,[9] addressing one of their primary health needs, menstrual health, could lead to health improvements for many people in these countries and at the same time improve the productivity of these sectors, through reduced absenteeism rates and increased output on the job. Using detailed production data from a larger set of factories in Bangladesh, we estimate that the 20 percent reduction of absenteeism that we see on average in the groups of workers that either receive free pads or attend the information sessions would lead to a 0.8 percent increase in line output. We can use the average monthly worker wage of 115USD in our sample to obtain a lower bound of 0.90USD on the value of the increased output per worker from such a reduction in absenteeism. Given the costs of providing free pads to workers of less than 0.42USD per worker and month, investing into female workers menstrual health could bring significant returns for the factories.

Beyond menstrual health, this paper also contributes to a larger literature on adoption of health promoting behaviour in developing countries. For example, Luby et al. (2004), Hussam et al. (2017) and Bennett et al. (2018) all test for the effectiveness of interventions promoting more frequent hand washing in Bangladesh and Pakistan. Lack of information and lack of habit formation are shown to slow down the adoption of this crucial health behaviour. On the other hand, interventions designed to change social norms around this behaviour seem less effective in this setting (Guiteras et al. (2016)). Meanwhile, an information campaign regarding unsafe drinking water in Bangladesh, with a clear and directly associated health risk, leads to large and swift behaviour changes (Madajewicz et al. (2007)). Regarding other health related behaviour, Banerjee et al. (2010) test for the effect of a vaccination campaign, including financial incentives, in rural India, while Rhee et al. (2005) and Cohen and Dupas (2010) study take-up of anti-malaria nets, with the latter showing that even small "symbolic" prices can deter take-up. Due to the stigmatised nature of menstruation, our paper is also close to studies on other stigmatised health problems, such as HIV (De Walque (2007); Dupas (2011); LoPiccalo et al. (2016)). These papers point towards the effectiveness of information campaigns, even if their effectiveness may correlate with general education levels of the recipients. Our contribution to this literature is to look at the adoption of a different health product, sanitary pads. And while this health concern shares its stigmatised

[8] See also the consultancy reports McKinsey (2011) and Impactt (2011, 2012, 2013) for more evidence on relatively high absenteeism and turnover rates in the Bangladeshi, Indian, and Chinese garment export sectors.

[9] For example, in a sample of 70 large garment factories in Bangladesh employing around 108,000 workers, 73 percent of all workers are female (Menzel and Woodruff (2019)).

nature with HIV, the fact that we address an arguably less imminent, more long-run and also less novel health risk, could make the adjustment of associated restrictive norms more challenging. Furthermore, menstrual health can be easily addressed by employers, who may directly benefit from doing so through reduced absenteeism, linking our study to the larger literature on management practices in developing countries (Bloom et al. (2012, 2013)). We furthermore aim to disentangle a more exhaustive list of possible constraints to adoption, namely financial, information, and taboo related constraints, while the above cited papers usually either focus on one of these constraints, or bundles of them which they struggle to separate.[10]

In the next section we present more details about the garment sector in Bangladesh, and the design of the randomised trial. We present the results on the adoption of pads in section 3 and the outcomes based on administrative data from the factories' HR departments in section 4. In section 5, we look at further self-reported outcomes regarding well-being, mobility, and social norms at the work-place and beyond. In section 6 we conclude.

## 3.2 Background and Data

The Bangladeshi garment sector emerged in the 1980s, and has grown rapidly ever since, employing more than four million workers today, more than 70 percent of whom are female (McKinsey (2011); Heath and Mobarak (2015); Menzel and Woodruff (2019)). Garment workers typically start working in the sector at the age of 18-20, and female workers largely leave the sector by the age of 30. One reason for that may be that unlike men, they have few opportunities to advance beyond basic sewing machine operator positions, e.g. to supervisor, quality inspector, or mechanic positions (Macchiavello et al. (2015); Menzel and Woodruff (2019)).

The sector is concentrated around the two largest cities of the country, Dhaka and Chittagong, and the majority of workers migrate to these industrial areas from the countryside. Factories are mostly locally owned and managed, and contract with international brands for the production of garments such as t-shirts, dress-shirts, pants, or jackets. Starting wages for both men and women without higher education or sector specific experience is around 60-70USD per month to work for six days per week and 8-12 hours per day, depending on overtime run by the factories. On the other hand, an experienced sewing machine operator can earn around 150USD per month, depending again on overtime worked.

[10]Oster and Thornton (2012) analyse a complementary determinant of take-up of a menstrual product (menstrual cups) to ours, spill-over within social networks of women.

For this trial, we work with three factories in Bangladesh that expressed interest in participation. Two factories nominated 200 female workers each for the trial, while the third nominated 600. The factories each employ between 1,200-1,800 female workers. Table 3.1 summarises characteristics of the 1,000 female workers in the sample. For some of the variables, we can compare the averages from our sample with the averages from a survey of ca. 1,600 randomly-drawn female sewing operators from 70 other factories in Bangladesh, analysed in more detail in Menzel and Woodruff (2019). Workers in our sample are on average 24 years old and report to have spent on average 6.9 years in school, compared to 5.7 schooling years in the larger survey, where workers are on average 25 years old.[11] 82 percent report to be married, close to the number in the extended sample, while 63 percent report having children, somewhat less than in the extended sample. The larger sample was collected between 2012-2017, whereas the baseline survey for this project was done in 2018. Therefore the relatively modest differences could represent cohort effects, particularly as schooling extended rapidly in recent decades in the country. Workers report that on average 2.6 people live in their household (including the worker herself). Based on administrative data from the factories, at baseline they earn on average 8,400BDT per month with overtime pay included, around 100USD, and miss on average 0.6 days of work each month without excuse (being "absent") and another 0.15 days with medical excuse ("sick leave").[12] Given a standard month of 24 production days, this implies that 3 percent of female workers are absent on an average working day. Absenteeism values are significantly higher in the extended sample of 70 factories, where the combined absenteeism rate is around 5 percent. It is not immediately clear from the data what causes these differences.

Turning to menstrual health practices among the sample of workers for our study, 41 percent report to use sanitary pads regularly at work, while 50 percent report to have never used it, with the remaining 9 percent using a mix between modern and traditional products.[13] The self-reported use of pads is strongly negatively correlated with age or having children, and strongly positively correlated

[11]Six workers in our sample report to be 17 years old, and two workers 15 and 16 years old, respectively. National laws prohibit the employment of minors in the sector, but the country is lacking a consistent ID system to verify worker age, and widespread poverty is pushing minors to seek employment also in the garment sector. More advanced factories use medical checks by medically trained staff to estimate worker age, but this system remains imperfect.

[12]Note that half way through the pad distribution period, with the start of the year 2019, the minimum wage in the sector was increased, resulting in a new average pay in our sample of 115USD per month.

[13]The share of workers using pads regularly varies between 37 percent and 53 percent across the three factories in our sample. These numbers also fit with the 40 percent of workers who report to use pads during their last period at a baseline survey for an in-house evaluation of an MHM project by the NGO SNV in 20 Bangladeshi garment factories (SNV (2017)).

with education. These variables, however, are correlated among themselves, and in a regression of baseline pad use on all of these variables, age looses its statistical significance, while the other two remain significant predictors. Self-reported use at baseline is also positively correlated with willingness to pay for pads, as elicited via the incentive-compatible Becker-DeGroot-Marschak mechanism (Becker et al. (1964)). 13 percent of workers in the sample report having missed work in the past 12 months due to menstrual health related problems, with 4 percent reporting having missed work due to a lack of adequate MHM products. We suspect that these values may represent a lower bound to the true extent of menstrual health related absenteeism, given that the surveys were done on factory premises.[14] 80 percent of workers in our sample report feeling more tired at work during their period, 70 percent state that they struggle more to reach their work targets, and 58 percent report worrying that their absorbant leaks during work. Thus, in our setting menstrual health does affect self-reported worker well-being and productivity in a first-order way.

### 3.2.1 Experimental Design

The randomised trial is designed to relax three main constraints to the broader use of modern hygienic MHM products: financial, information, and taboo related constraints. The basic design is a two-by-two trial with two cross-randomised main treatment arms, generating four treatment cells of equal size (250 workers per cell). All randomisation is stratified at the level of the three participating factories. The first main treatment arm is access to free sanitary pads at the factory premises, to relax the financial constraint. More precisely, workers randomised into this treatment can collect one pack of eight sanitary pads per month from the "medical rooms" of the factories during lunch-breaks, whose locations are typically well-known to workers.[15] All workers in the sample who do not receive access to free pads receive a placebo present (beauty kit) of comparable value, to counteract wealth effects on our outcomes. At the two factories that nominated 200 workers for the trial, the pads can be collected during two days of the week, while at the third factory that nominated 600 workers, they can be collected four days per week. The days in the week are always the same over time at the individual factories, to minimise

[14] Note however, that no factory staff was allowed into the rooms in which we conducted the surveys at the factories, and workers were told that no information at the individual level would be shared with the factory management.

[15] We limit the number of free pads a worker can collect to one pack of eight pads per month, to reduce the possibility of workers sharing pads with others not randomised into this treatment, which would cause spill-overs that would bias downwards the estimates of our treatment effects.

confusion for workers. On the respective days, the pads can be collected from a distribution worker stationed in the medical room and employed by us for the project, who checks eligibility of the workers looking for pads, and hands out the pack of pads.

The second main treatment arm, addressing the information constraint, is the attendance of a 45 minute long information and awareness session conducted by the staff of an experienced NGO, which has conducted such sessions for many years in other garment factories in the country. The sessions are held during work time, so only workers absent from work on the days the sessions are held do not attend them (conditional on being randomised into this treatment). The sessions provide an anatomical background for what causes menstruation and stress the importance of hygienic MHM, either through the use of modern disposable absorbants (disposable sanitary pads) or through washing of reusable absorbants and subsequent drying of them in the sun. Furthermore, the sessions provide advice for remedies against period pain and for communicating about MHM with adolescent girls. The NGO generally provides these courses to a mixed audience of male and female workers, but for our project the sessions are held for a purely female audience, to minimise the project complexity and possible sources of distraction of the participants during the sessions.

Taboo based constraints are addressed through two variations in the two main treatment arms. In the free access to pads treatment, the medical room in which workers can collect the pads is staffed on one day per week by a male, and the other day by a female distribution worker (two days per week each in the factory with four distribution days). The days in the week with the male and female distribution workers are swapped each month, to avoid confounding the effect of the sex of the distribution worker on collection rates with day of the week effects. The basic outcome of interest is whether workers are more likely to collect the pads from the female distribution worker than from the male. This would be predicted by the widely held concern in the country that women do not adopt sanitary pads in larger numbers because the shops selling them are mainly staffed by males, with the taboo encompassing menstruation being more salient in cross-gender interactions.

The second way we address taboo-based constraints is by randomly varying the information content in the information and awareness sessions. While half of them (attended by around 20 workers per session) focus solely on the established medical and hygiene message of the NGO, the other half of the sessions contain an additional 10 minutes long module at the end, in which the teacher demonstrates the better absorbing capacity of sanitary pads compared to traditionally used cloth.

For this test, actual pads, cloth and blue liquid are used, not unlike what is shown in TV adds for sanitary pads in Bangladesh and elsewhere. The teacher engages some workers from the audience in the trial, creating an interactive teaching experience, and stressing that using pads not only has health benefits but also reduces the risk of absorbant leakage, a main worry of workers during their period, as already shown in the summary statistics above. Workers are randomised into whether they attend a session with or without this additional module, allowing us to test whether a message of minimising the risk of the major stigma triggering incident – leakage during work – has a separate additional effect on pad adoption.

### 3.2.2 Balance and Attrition

To test balance, we regress 50 worker observables (38 based on baseline surveys and 12 based on administrative HR data) on five dummies for the five treatment categories: (i) free pads without information session, (ii) free pads with information session, (iii) only information session, while (iv) and (v) are interactions of the latter two for information sessions that also include the "stigma module" discussed in the previous sub-section. Table 3.2 reports p-values from F-Tests for the joint significance of the five treatment allocation dummies. Among the 50 variables, the joint significance is below the 5 percent level for only one variable (hourly overtime pay rate from administrative data), and below the 10 percent level for only one further variable (social appropriateness of discussing period aspects with mother).

We have an attrition rate of 11.9 percent from baseline to endline. These are workers who we neither manage to survey at the factory at endline, nor reach in the endline phone survey that we conduct among the remaining workers. We test whether attrition is differential in each of the three main treatment groups relative to the control group along the 50 worker observables, which implies 150 individual statistical tests. Of these, the tests are significant at the 5 percent level for seven comparisons, and at the 10 percent level for 22 comparisons (none are at the 1 percent level), pointing to only minor, and at most marginally statistically significant differential attrition.[16]

[16] For example, relative to the control group, non-attriting workers in some treatment groups are slightly older (information only), slightly more likely to be married (free pads with information), less likely to still live with parents (information only), earn more (free pads only), or have slightly higher absenteeism rates (information only). We control for workers age and marital status in all basic regressions, and in HR data based analysis, we use worker fixed effects in difference in difference specifications that control for time invariant worker characteristics.

### 3.2.3 Treatment Uptake

The take-up of the information treatment is near perfect, as it is done during work time, with the factory management instructing the workers randomised into this treatment to attend the sessions. Meanwhile, Figure 3.1 shows the uptake of the access to free pads treatment. The solid lines show, for each month and each of the three participating factories, the share of eligible workers collecting their package of pads from the distribution worker. The line for Factory 3 starts only in November 2018, as baseline surveys had only finished by that time, while the treatment had already started at the other two factories. While at two of the three factories (including the one that contributed 60 percent of the sample), collection rates at the first month available for collection are 70-80 percent, they are less than 20 percent at the third factory.

For the following months, collection rates follow a slight downward trend at the two factories with high collection rates, which is mainly explained by the continued exit of workers in the sample from the factories, as indicated by the dash-dotted lines.[17] Conditional on still working at the factory, collection rates remain between 70-80 percent, only dropping off at the last month of distribution, May 2019. This month coincides with Ramadan, a time of heightened production pressure before the most important holiday of the year in the country, Eid al-Fitr, around which factories close for 1-2 weeks. Meanwhile, among workers still working in the factory, collection rates reach 25-30 percent at the third factory after a few months of distribution, but then collapse to almost zero at the last two months. The main reason we eventually learned for the low collection rates at that factory is that both the collection room and the collection times during the lunch-breaks are inconvenient for the workers at this factory.

Meanwhile, Figure 3.1 already reveals a first result on the hypotheses laid out above, with the dashed lines indicating the share of pads collected each month from the male distribution worker at the three factories. Workers collect pads at roughly equal rates from the male and female distribution workers at each of the three factories. In fact, more of the pads are collected from the male distribution worker at 15 of the 23 factory-months of distribution, and also overall, more pads are collected from the male than from the female distribution worker. This is *prima facie* evidence against the hypothesis that workers prefer to obtain pads from female distributors. Interestingly, the workers collect pads at higher rates from the female distribution

[17] The drop in collection rates at "Factory 1" in December is due to unrest in the industrial area surrounding this factory in connection with the controversial increase of the minimum wage of the sector at that time, with the unrest leading to the closure of the factory for more than a week.

worker during the first month of distribution at each of the three factories. This indicates that workers may quickly overcome any initial reluctance to obtain pads from male distribution workers. Nevertheless, these results are not consistent with the hypothesis that women have a strong preference to obtain pads from other women.

We can also look at the correlates of pad collection (or treatment uptake) among workers who are randomly provided access to the pads. As shown in Table 3.3, older workers are more likely to collect the pads, while interestingly, workers with a higher willingness to pay have a lower take-up. We saw above that willingness to pay is positively correlated with pad use at baseline. Thus, it may be likely that these workers already have established access to pads for everyday use, and are therefore less in need for pads. On the other hand, workers in general who reported using pads at baseline are neither more nor less likely to collect the pads, if randomised into this treatment arm. Being randomised also into attending the information session is positively correlated with collection rates, mainly among those workers who do not report using pads at baseline, implying that information is complementary to pad adoption. Finally, and possibly most surprisingly, the information treatment do not have an effect on pad collection when it includes the stigma module on the superior absorbing capacity of pads (regardless of whether the worker use pads at baseline or not).

## 3.3 Adoption of Pads

Before showing results for the different treatment arms on outcomes such as worker absenteeism, well-being, or adherence to taboos, we first show results on the intermediary outcome of pad use, as reported by workers at the endline survey. Pad use is both of interest in its own right, given the health benefits associated with modern hygienic MHM products, and as a first check whether the treatment arms have their desired first stage effects on increased adoption of hygienic MHM products.[18] We note that the endline survey is done during the last month of distribution of free pads. Thus, increased pad use among workers randomised into the free pad treatment arm would be consistent with these workers reporting higher use because they collect and use the free pads. Thus, heightened pad use rates in this case would

[18]In principle, other "modern" MHM products such as tampons, menstrual cups, or reusable pads (if cleaned properly after use) have similar health benefits as disposable sanitary pads. However, tampons or menstrual cups are largely unknown in our setting, while the benefits of reusable pads depend on their proper cleaning and drying after use, which due to lack of knowledge and prevailing taboos is not universal. For that reason, in this study, we equate "modern" MHM products with disposable sanitary pads.

implies that offering free pads does lead to higher pad use rates, or that the price of sanitary pads is a binding constraint on their adoption. On the other hand, this implies that our current results should not be readily interpreted from a learning perspective, insofar that access to free pads allows workers to learn about the benefits of pads and start purchasing them at market rates. Whether this particular learning mechanism is active in our trial or not will have to be left for later research, through surveys on pad use after the distribution of free pads has ended. However, we can test already whether the treatments affect willingness to pay for pads at the endline survey, which would be consistent with learning effects.

Table 3.4 shows the effects of the different treatment arms on self-reported pad use at baseline. Pad use was asked on a four-step Likert scale on whether the worker uses pads "always", "often", "sometimes", or "never". However, to better interpret our results, we define a dummy variable taking value one for using pads "always" or "often", and value zero for "sometimes" or "never" as main outcome variable for this table (results are qualitatively the same when using the four-scale measure directly, and also with ordered probit, as shown Table 3.9 of Appendix A). Column 1 shows that workers randomised into the free pad treatment are ca. 10 percentage points more likely to use pads at endline, while workers who attend the information session are around 7 percentage points more likely. The effects seem not to be additive; workers who receive both access to free pads and attend the information session are not more likely to use pads than those workers who only have access to free pads. These results remain unchanged when controlling for a battery of worker observables (column 2).[19] As expected, the results are entirely driven by workers who report to not have used pads at baseline, for whom the effects are about twice as large (column 3). The effects of access to free pads are larger among those workers still working at the factory at endline, with access to free pads increasing the self-reported pad use rate by 22 percentage points among those who did not use pads at baseline (column 4), though the differences in the coefficients

[19]They also remain qualitatively unchanged when applying Lee bounds to address the attrition of 119 workers from the sample. Setting pad adoption for all these workers who could not be interviewed at endline either equal to zero (no pad use) or one (pad use) does not change the estimated coefficients or standard errors qualitatively.

from column 3 are not statistically significant.[20,21]

Again perhaps surprisingly, but consistent with the results from Table 3.1, the information session have a weaker effect on adoption when including the additional stigma module, with the difference to the effect of the information treatment without this module, being statistically significant among the workers who get access to both free pads and the information session (column 5 of Table 3.4). While we prefer to defer further discussions of possible reasons for this negative effect to after further data collection, we note that both our experimental variations aiming to detect whether taboos are binding constraints to pad adoption do not show the effects that would be consistent with that hypothesis being true. Thus, even though we will show that workers in our sample do adhere to some of the common taboos on menstruation, these taboos do not seem to constrain pad adoption in this setting, at least not along the explicit dimensions we varied their salience.

Finally, we remark that even the control group exhibits a large increase in self-reported pad use from baseline to endline survey, from 46 percent that reported using pads "always" or "often" to 83 percent. 73 percent of workers from the control group who reported to not have used pads at baseline reported to use them at endline. This increase must be due to some combination of time trends in pad adoption, spill-overs from treated groups, the effects of going through a detailed 30-minutes long baseline survey on MHM practice on subsequent pad adoption, and some form of desirability bias in reporting to use pads that is triggered by a repeated survey on MHM practice, after having already gone through the baseline survey (see Zwane et al. (2011); Dupas and Miguel (2017) on discussions of the latter two effects).

To at least separate the first two from the latter two effects, we survey shortly after the end of the endline surveys an additional sample of 200 female workers at the three factories, proportional to the number of workers from each factory in the main sample. These workers have not been part of any previous activity related to the project, such as surveys or treatments. Thus, their average pad use rate can be regarded as free of survey effects or repeated-survey desirability effects. However, as these additional 200 workers are not randomised into this role, we have to be careful

[20] We conducted phone surveys with those workers not working at the factories anymore by the time of the endline, in which we managed to reach 105 out of the 224 of these workers.

[21] Note that the three main independent variables are group-specific treatment indicator variables for each of the three treatment groups of free pads, information session, and free pads plus information session. In particular, the coefficient on the free pads plus information sessions treatment shows the difference in the mean of outcome variables between that treatment group and the control group. Thus, one does *not* need to add up the three treatment group coefficients to get the mean outcome differences between control group and free pads plus information session treatment group. This also holds for all further tables in the paper.

in interpreting differences in pad use rates between these 200 workers and the 250 from the main sample randomised into the control group. Thus, we use propensity score matching (nearest neighbour, with replacement) to assign each worker from the main sample's control group a matched worker from the additionally surveyed women from the same factory. In the matched sample, the pad use rate is 70 percent, or 13 percentage points less than the 83 percent of workers from the control group who report using pads at baseline.[22] Therefore, 13 of the 37 percentage points of the increase in reported pad use rate for the control group from baseline to endline, is estimated to be due to survey effects or desirability effects in repeated surveys, while the remaining 24 are time trends, or spill-over from the treated groups.[23]

## 3.4 Worker Outcomes Based on Administrative HR Data

Having seen that workers randomised into the free pads or information treatments are more likely to report using sanitary pads at baseline, we next study whether we see effects on the main outcome variables that we collect in form of monthly HR records for individual workers. Our main outcome variables of interest are worker absenteeism, overtime hours, earnings, and worker turnover. So far, we have collected these variables starting from April 2018, half a year before the start of the interventions, until May 2019, seven months after the intervention. Thus, we can run difference in difference specifications, for example with worker fixed effects and treatment arm specific dummy variables indicating that the observation is from a post-treatment start month.

Figure 3.2 shows mean values for our primary outcome variable of interest, worker absenteeism, for each of the three main treatment cells and the control

[22] We match on pay-grade, age, years of schooling, and whether worker has any child. We match exactly on working in the same factory. In the raw data from the 200 additional surveys, the pad use rate is 59 percent.

[23] We plan to implement two additional features to the design of the study in the second iteration of the trial that will help us better disentangling these possible drivers of an increase in pad adoption in the control group. First, we will have two control groups into which workers are randomised. One which goes through the standard baseline survey with lengthy modules on current menstrual practices and attitudes, and one which only goes through a brief demographic background module in the baseline survey. This overcomes the need for matching workers in the sample with workers from outside the sample to separate out survey effects on (reported) adoption. Second, we will collect network data among the sample of workers at baseline. Spill-over effects from treatment to control groups are likely to occur mostly along established social ties between workers, both in terms of sharing (freely collected) pads, and in terms of sharing information received in the sessions (compare Bandiera and Rasul (2006) andConley and Udry (2010), who show that take-up of new agricultural technologies spreads mainly along social network lines, or Banerjee et al. (2013) andCai et al. (2015) who show the same for take-up of new microfinance services). Thus, network data would allow to disentangle time trend and spill-over effects in network adoption.

group, for seven months prior to seven months after the start of the treatment at the factory.[24] Before turning to differences in means between the groups, we note a large spike in absenteeism in the second month of treatment. This spike is entirely driven by the data from one factory, which is located in an area that experienced worker unrest related to a controversial increase in the sector's minimum wage. This factory contributes 200 workers to our sample. The dashed lines in the graph indicate how the group specific trends look if, for that one month, we drop these 200 workers from the sample. In this case the means for that month are in line with the overall trends in the data. Since such spike in absenteeism likely introduces a lot of noise in the data, our preferred sample does not include the observations from the 200 workers from that factory for that month, though we show results with and without including these observations in the estimation.

To see more clearly if the time series of means for the different groups behave differently pre- and post-treatment start, Figure 3.3 plots the deviations of the monthly means of the three main treatment groups from those of the control group, including 95 percent confidence intervals. The picture is not clear cut, possibly because we have not yet reached our targeted final sample size. However, the trends in absenteeism of the pad-only and the information-only treatment groups experience a drop around the start of the treatment relative to that of the control group, though month-specific confidence intervals mostly still include the zero. No trend is visible for the group of workers who receive both treatments. To test if the average reductions in absenteeism over the months after the start of the treatment relative to the months before are statistically significant, and to control for further worker observables, Table 3.5 shows the results of running the following difference in difference model on this data:

$$Y_{ifm} = \beta^G T_m^G + \gamma_i + \delta_{fm} + \epsilon_{ifm} \tag{3.1}$$

$T_m^G$ is a set of three treatment dummies for randomisation into the three main treatment groups $G$ (Free Pads, Information Session, Free Pads & Information Session), taking value 1 for post-treatment months $m$ (or post-treatment start in case of the free pad treatments). Thus, $\beta^G$ are ITT treatment effects of the three treatment arms $G$. Meanwhile, $\gamma_i$ is a set of worker fixed effects, controlling for time-invariant characteristics of workers, $\delta_{fm}$ is a set of fixed effects on the factory-month level, controlling for factory-specific time trends and seasonality, while $\epsilon_{ifm}$ is the error term. Standard errors are clustered at the worker level.

[24]Pre- and post-month to treatment start are normalised across factories, as in one factory the treatments started a month later than at the two other factories, for logistical reasons.

Table 3.5, column 1, shows the results of estimating equation 3.1 using monthly number of worker's absent days as outcome variable, as in Figures 3.2 and 3.3. We can see a marginally negative effect on absenteeism among those workers who only attend the information session. The effect among the workers who only receive free pads is slightly smaller and its p-value is just above conventional levels for statistical significance (0.122). If we drop the one month of data from the factory suffering from unrest, as discussed above, the coefficients become larger, and their statistical significance increases to the five and ten percent level, respectively, as shown in column 4 of the table. Given an average absenteeism level of 0.64 days per month in the control group, we estimate that either access to free pads or attending the information session reduces absenteeism by around 15 percent and 25 percent, respectively, given the coefficient sizes. Surprisingly, though, no such effect is visible among the group that both has access to free pads and attend the information session. Our trial does not provide us with an answer for the lack of effect among this group. In the pre-treatment period, absenteeism rates in this group seem to fluctuate more widely compared to the other groups, as can be seen in Figure 3.3. The planned repetition of the trial with additional 1,000 workers from further factories provides a useful opportunity to see if this pattern replicates, which would indicate a non-zero interaction effect of the two main treatments on worker behaviour.

Regarding overtime hours, we do not find any statistically significant effects (columns 2 and 5, Table 3.5). It is not clear ex-ante what effect to expect. On the one hand, if the treatments make workers more productive, they could finish their daily assignment earlier, reducing overtime needs. On the other hand, it could make them volunteer for overtime, to increase earnings, as overtime is, by law, paid at 150 percent of the standard hourly rate of a worker. However, we show the effects as we specified this outcome in the pre-analysis plan. With respect to earnings, we find a marginally significant effect of the free pads only treatment arm, increasing earnings by around 1.7 percent relative to the average earnings of the control group of around 9,700BDT (column 6, Table 3.5). However, in the pre-treatment period, earnings in that treatment group are on average marginally significantly lower, so the effect may at least partly be a return to the mean effect (see Figure 3.4). On the other hand, it could be explained by the reduction in absenteeism in that treatment group which comes along with the treatment. In fact, controlling for absenteeism reduces the coefficient on this treatment by around a quarter, and the p-value to 19 percent (column 7).

A final important outcome variable is worker turnover, which has been often cited by local industry insiders as a main constraint on operational productivity growth (McKinsey (2011)). We create an outcome variable measuring whether the worker still works at the factory at the time of the endline survey, based on monthly HR records, and regress it on the treatment indicator variables. While all three main treatment groups show positive coefficients, none are statistically significant at conventional levels (with the coefficient on the information treatment having a p-value of 0.13).

To conclude, we do find some statistically and economically meaningful effects of our two main treatments on at least one of our main outcome variables, worker absenteeism as measured by factory administrative data. However, combined, the two treatments do not have the same effect. These results are not statistically significantly different for workers who report using pads at baseline. Neither does the additional stigma module in the information session affects the outcomes (see Table 3.10 in Appendix A), concurrent with them not increasing pad collection or general pad take-up. In the next section, we test how the treatments affect self-reported well-being at work, behaviours and social norms beyond the workplace.

## 3.5 Work Place Satisfaction, Norms and Behaviour beyond Work

### 3.5.1 Willingness to Pay for Sanitary Pads

This section analyses the data from the endline survey conducted after six months of distribution of free pads. We first look at willingness to pay. Given the positive effects on absenteeism from Table 3.5, which also seem to translate into earnings, we may expect that workers willingness to pay for pads is positively affected by the treatments. A positive effect on willingness to pay, particularly in the free-pad treatment, would also point towards a learning mechanism. Access to free pads allows workers to learn about the utility they can provide, and thus update their willingness to pay. We elicit willingness to pay at baseline and endline survey using the experimental Becker-DeGroot-Marschak mechanism, which is incentive compatible with providing truthful information on valuation of goods (Becker et al. (1964)). Table 3.6 shows the effects of regressing willingness to pay at endline on the treatment indicator variables, controlling for a number of workers characteristics, including willingness to pay at baseline. We find a marginally significant positive effect from the free pad-only treatment, amounting to an eight percent higher willingness to pay compared to the control group, but not from the information treatment, or among workers with access to both treatments. While it is again surprising to see that the combined treatment has no effect, these results are at least consistent with those workers who have access to free pads and experience positive effects on absenteeism increasing their willingness to pay. The additional stigma module in the information session has a positive effect, though it is not statistically significant (p-value of 0.11 in the group that also receives free pads - column 2). Interaction effects with having used pads already at baseline do not show systematic effects (column 3).

### 3.5.2 Self-reported Well-being at Work

Table 3.7 tests for effects of our treatments on a battery of eight self-reported dimensions of well-being at work, such as if workers feel tired during their period, whether it is more difficult to reach their work targets, whether they worry about leakage of their absorbant or about odour, or whether they feel isolated during the period, or more easily irritated. In short, we do not find much effects on these self-reported outcomes. Workers who attend the information session (but do not receive free pads) report feeling more energetic during their period by endline. On the other hand, we see a negative statistically significant effect of free pads on whether workers report to find it easy to reach their work targets among the workers who receive free pads only. This effect goes against our prior that access to modern MHM products should make work easier at the margin. Given the fairly large number of estimated coefficients shown in this table, this negative effect may by a statistical outlier.

To reduce the number of estimated coefficients, we also create two summary variables over the eight outcomes, one summarising the four "ease of work" variables (tiredness, targets, energy, irritation), and one summarising the four "psychological burden" variables (shame, isolation, worry about leakage and odour), using principal component analysis. However, as shown in the last two columns of Table 3.7, we only find insignificant effects on these variables.

### 3.5.3 Mobility, Behaviour and Social Norms beyond the Workplace

Even if the trial is conducted within a work-place context, we expect it to affect behaviour and social norms beyond the workplace as well. For example, the information sessions discuss content beyond the work-place, as how to communicate about MHM with family members, or relaxation exercises against period pain. Table 3.8 summarises in its three panels the results of the treatment arms on three types of outcome variables: simple self-reported behaviour and mobility during period (Panel 1), injunctive social norms, or what the worker thinks about what norms say the worker *should* do regarding these behaviours (Panel 2), and descriptive norms, or what the worker thinks the majority of her peers do (Panel 3) (Bicchieri (2005); Bicchieri and Dimant (2019)). The questions shown in Panel 2 and 3 are incentivised to reveal perceived norms, not personal preferences. Workers receive a small payment if their answer on a four-item Likert scale on the appropriateness (Panel 2) or commonality (Panel 3) of a given behaviour matches the modal answer among other workers in the factory.[25] Thus, the questions reveal whether the treatments change the worker's behaviour (Panel 1), whether the treatments lead the workers to update their understanding of social norms on that behaviour (Panel 2), or their understanding about majority behaviour among their peers (Panel 3).

We can see consistent changes in both personal behaviour and understanding of social norms for two behaviours in Table 3.8, both towards less adherence with restrictive traditional taboos. The first is on the common taboo in the region that women should not eat with others during her period.[26] As shown in column 2, women who receive free pads and attend the information session report to be more likely to eat jointly with their family members during their period, and perceive this practice to be more common among their peers. The effect on own behaviour is also visible among those women who only attend the information session. The effect is not just family specific. As shown in column 3, also (injunctive and descriptive) norms against eating with non-family members are loosened, at least among those workers who receive both treatments.

The second consistent effect we observe is a lower adherence to the taboo that one should not dry the cloth used during menstruation outside, after washing it (column 8). Again, this is one of the most prominent taboos in South Asia surrounding menstruation (Ahmed and Yesmin (2008)). This taboo has particularly negative implications for women and it leads them to dry the cloth inside the house, often inside cupboards to shield it from the views of even family members. This prevents the cloth from properly drying, keeping it damp and increasing the health risk associated with its use. Instead, if dried outside, the sun's UV light would disinfect the cloth. This taboo is also directly addressed in the core curriculum of the information session on good MHM practice. Therefore, the positive effects in Panel 1 on own behaviour may be confounded by recall bias. Workers remember what they learned at the information session, and reproduce it at the endline survey. However, the effects on this taboo are even stronger when looking at the answers to

[25] After the worker goes through all the questions on injunctive and descriptive norms, respectively, one question in each set is randomly chosen and compared to the modal answer, to determine whether the worker receives the bonus.

[26] It is one manifestation of the common stigmatisation of menstruating women in South Asia that separates them from other family members in all kind of household activities, in extreme forms making them sleep outside the family dwelling (Ahmed and Yesmin (2008)).

the incentivised questions on injunctive and descriptive norms. This suggests that workers indeed adjust their views on what their peers find appropriate.

The two taboos discussed in the last two paragraphs lie on opposite extremes in terms of their prevailing strength in this context, as represented by the "Mean Control Group" statistic in each Panel of Table 3.8, which shows how much workers in the control group adhere to the taboo at endline. A lower value on the 0-3 scale means stronger adherence, showing that the taboo to not dry the cloth outside is still adhered to strongly. On the other hand, the taboo on not eating with others during one's period, in particular family members, is already not widely followed anymore in this setting.

We see a number of effects of specific treatments in certain panels, loosening a number of further taboos, for example to not go to the market during period, or to not visit newborns. However, these effects lack both consistency across the three panels, and across the treatment cells, unlike the effects on the two taboos previously discussed. Furthermore, the treatments mostly have effects on traditional norms, but less on mobility not subject to norms. For example, we find no effects on the likelihood that workers report not walking long distances or using buses during their period.

Finally, the table presents a contradictory set of treatment effects on the taboo for a women to not going to religious sites during her period (Garg et al. (2001); Ahmed and Yesmin (2008); Dasgupta and Sarkar (2008)).[27] The taboo is still very strongly reproduced among the workers, as shown by very low mean values among control workers. For example, in the incentivised norms questions in Panels 2 and 3, practically every control worker reports that the taboo is still widely followed. We see some effects on loosening the injunctive norm on avoiding religious sites among workers who receive free pads (with or without information session). On the other hand, in Panel 1, the same workers are more likely to report adhering to this taboo in their personal behaviour, and we also see a concurrent effect among the workers in the information only treatment group. We do not see any effect on descriptive norms. Given the inconsistent results on this dimension, we postpone the final discussion of these effects until we can study them on the final, complete sample of the study.

[27]Mosques, and temples among the sizeable Hindu minority in Bangladesh (ca. 10 percent of population). Hindus are also relatively well represented among workers in the country's garment sector.

## 3.6 Conclusion

We present the results of the first randomised trial that, to the best of our knowledge, distributes free hygienic menstrual health products (disposable sanitary pads) to poor working women in a developing country context, the Bangladeshi garment export sector. Awareness and information sessions on hygienic menstrual health management (MHM) by an experienced NGO were cross-randomised with the free pad treatment, in order to alleviate possible information constraints on the adoption of pads. We also vary exogenously the sex of the distribution worker from which the pads can be collected by eligible workers, as well as the information content of the awareness sessions, between a solely medical message and additional messages showing that sanitary pads are more reliable compared to traditional remedies in reducing the risk of leakage. We have so far implemented the trial on a sample of 1,000 workers, and are planning to conduct it with 1,000 additional workers before the end of the year 2020. This paper presents the results on our main outcome variables from the first half of the sample.

We find that both information provision and the provision of free pads increase self-reported use of pads relative to the control group. At the same time, we also observe a substantial increase in pad use in the control group, suggesting survey effects on MHM behaviour, next to spill-over effects to the control group and general time trends in pad adoption. We find effects of both free pads and the information sessions on reduced worker absenteeism, though not in the group of workers who are randomised into both treatments. We postpone discussions of possible reasons for this pattern until we can test if it replicates in the second round of implementation of the trial. We find some effects on willingness to pay for workers assigned to the pads only treatment, no systematic effects on self-reported well-being at work, but meaningful effects on adherence to traditional restrictive taboos with adverse health consequences, both in terms of personal behaviour and in terms of perception of the strength of the underlying social norms.

Turning to our original classification of possible constraints to the more widespread of adoption of sanitary pads – financial, information, and taboo based – our results point towards both financial and information constraints being binding. On the other hand, experimentally varying the salience of taboos in the process of obtaining menstrual pads, either by removing a commonly named source of stigmatisation (male clerks at points of access to pads), or by demonstrating the higher reliability of pads in preventing stigmatised situations (leakages), does not affect the outcomes in any systematic way. Evidently, these variations may not capture the binding dimensions of menstrual taboos in this context, and we plan to test for additional dimensions of taboos in the remaining sample for this study.

However, if cost and lack of information turn out to be the binding constraints to adoption, and if loosening them leads to reduced worker absenteeism, then providing free pads could be a promising investment for these factories in Bangladesh, and similar factories elsewhere. To gauge the returns for the factories from investing in their female worker's menstrual health, we use production data from Macchiavello et al. (2015), with daily, line-wise output and absenteeism data for all lines in seven factories in Bangladesh over one year. Using line and factory-month fixed effects, and assuming that the number of workers absent on a given day and line is as good as an exogenous shock for the factories, we estimate that a one standard deviation reduction in daily absenteeism increases daily output by 0.065 standard deviations. A 20 percent reduction of absenteeism, as we estimated in some of our treatment groups, would increase output by around 0.8 percent. Meanwhile, we can establish an absolute lower bound on the revenue per worker that these factories must make, on the assumption that it has to cover at the very minimum the worker's wage, which is on average 115USD per month in our sample (after the minimum wage increase at the beginning of 2019). Thus, an increase in output of 0.8 percent would imply at a minimum an increase in revenue of 0.90USD per worker and month. The packs of eight pads we distribute each month currently cost less than 0.42USD for wholesale in Bangladesh, despite being introduced in the country only a few years ago. Thus, further price reductions could be expected. But it suggests that already now the factories would reap a sizeable return on distributing pads to their workers.[28] Since this does not yet include the positive externalities on worker welfare through improved MHM, government subsidies for factories to offer pads, or even regulatory requirements to do so, can be considered.

[28]The share of labor costs over revenues is commonly reported to be below 20 percent in the sector, with material inputs (fabrics) by far the largest cost factor. Thus, even if the reduced absenteeism comes at a higher wage bill, as the factories can offset some of the costs of absenteeism through lower wage payments to the workers, this should be more than made up through higher revenue.

## 3.7 Tables

**Table 3.1:** Worker Characteristics

| | Trial Sample | | | | Menzel and Woodruff (2019) | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Min | Max | N | Mean | Min | Max | N |
| Age | 24.0 | 15 | 43 | 1,000 | 25.1 | 16 | 35 | 1,599 |
| Years of Schooling | 6.91 | 0 | 17 | 1,000 | 5.68 | 0 | 12 | 1,588 |
| Married | 0.82 | 0 | 1 | 1,000 | 0.83 | 0 | 1 | 1,599 |
| Children | 0.63 | 0 | 1 | 1,000 | 0.77 | 0 | 1 | 801 |
| People in Houshold | 2.57 | 1 | 7 | 1,000 | | | | |
| Village Origin | 0.97 | 0 | 1 | 982 | | | | |
| Sanitary Pads Regular | 0.41 | 0 | 1 | 1,000 | | | | |
| Sanitary Pads Never | 0.50 | 0 | 1 | 1,000 | | | | |
| Period - Absent | 0.13 | 0 | 1 | 1,000 | | | | |
| Period - Absent, no MHM Product | 0.04 | 0 | 1 | 1,000 | | | | |
| Period - More Tired | 0.81 | 0 | 1 | 1,000 | | | | |
| Period - Difficult Target | 0.71 | 0 | 1 | 1,000 | | | | |
| Period - Worry Leak | 0.58 | 0 | 1 | 1,000 | | | | |
| Wage (BD Taka) | 8,389 | 4,900 | 15,600 | 797 | 7,508 | 0 | 19,487 | 56,716 |
| Monthly Absent Days | 0.61 | 0 | 5 | 997 | 0.98 | 0 | 31 | 46,810 |
| Monthly Sick | 0.15 | 0 | 1.46 | 200 | 0.23 | 0 | 14 | 8,499 |

Notes: Table shows mean, minimum and maximum values of observable worker characteristics in our data for the 1,000 workers nominated by the participating three factories for the trial. Right-hand side panel shows comparison values from data collected from representative set of workers from 70 garment export factories in Bangladesh in 2012-2017, and analysed in Menzel and Woodruff (2019), for those variables available in both datasets.

**Table 3.2:** Treament Balance

| | Mean Control | F-Test: Six Treatments |
|---|---|---|
| *Survey Data:* | | |
| Grade | 4.672 | 0.835 |
| Age | 23.76 | 0.511 |
| Years of Schooling | 6.752 | 0.583 |
| Married | 0.820 | 0.215 |
| Husband same Factory | 0.178 | 0.423 |
| Number Children | 0.832 | 0.694 |
| Any Children | 0.624 | 0.516 |
| Number Boys | 0.404 | 0.721 |
| Number Girls | 0.428 | 0.872 |
| Age Youngest Child | 5.91 | 0.668 |
| Household Size | 2.59 | 0.598 |
| Living with Husband | 0.772 | 0.625 |
| Living with Mother | 0.128 | 0.520 |
| Living with Father | 0.088 | 0.785 |
| Living with Sister | 0.076 | 0.822 |
| Living with Brother | 0.52 | 0.726 |
| Living with In-Laws | 0.048 | 0.753 |
| Living Alone | 0.084 | 0.583 |
| Share Bathroom | 0.46 | 0.270 |
| Absent due to Period | 0.104 | 0.505 |
| Absent, Lack of MHM Product | 0.036 | 0.922 |
| Absent, Afraid Leakage | 0.012 | 0.836 |
| Period Tired | 1.792 | 0.614 |
| Period, Reach Target Harder | 2.140 | 0.817 |
| Period, Feel Ashamed | 2.284 | 0.145 |
| Period, Worry Odour | 2.672 | 0.987 |
| Period, Irritated | 2.02 | 0.600 |
| Norm: No Cooking | 3.668 | 0.911 |
| Norm: Eat with Husband | 3.804 | 0.753 |
| Norm: Eat with Others | 3.352 | 0.795 |
| Norm: Go to Religious Site | 1.02 | 0.523 |
| Norm: Go to Bazaar | 2.696 | 0.420 |
| Norm: Go to Workplace | 3.760 | 0.641 |
| Norm: Buy Pad | 3.604 | 0.958 |
| Norm: Talk Period Mother | 3.908 | 0.098* |
| Norm: Talk Period Husband | 3.916 | 0.248 |
| Norm: Dry Pad Outside | 2.196 | 0.633 |
| Willingness to Pay, Pad | 29.878 | 0.932 |
| *Administrative Data:* | | |
| Grade | 4.488 | 0.205 |
| Gross Salary | 7154.7 | 0.210 |
| Present Days | 22.09 | 0.290 |
| Absent Days | 0.577 | 0.371 |
| Sick Days | 0.033 | 0.322 |
| Attendance Bonus | 451.4 | 0.421 |
| Absenteeism Deduction | 80.92 | 0.555 |
| Overtime Hours | 33.80 | 0.942 |
| Overtime Rate | 42.25 | 0.012** |
| Paid Wage | 8330.1 | 0.421 |
| Late Arrival 1 | 0.037 | 0.250 |
| Late Arrival 2 | 0.217 | 0.319 |

Notes: OLS regression of each variable on set of five dummies for following randomly allocated treatments: Free Pads - No Info sessions, Free Pads + Info Sessions + No Stigma Module, Free Pads + Info Sessions + Stigma Module, No Pads + Info Sessions + No Stigma Module, No Pads + Info Sessions + Stigma Module. Second column reports p-values from F-Test on joint significance of all five dummies. Administrative data averaged between July-September 2018. Robust standard errors in parentheses: * $<$ 0.1, ** $<$ 0.05, *** $<$ 0.01.

**Table 3.3:** Correlates of Pad Collection among Eligible Workers

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Dependent Variable: | Collect Free Pads (months) | | | | |
| Information Session | | 0.349 | 0.532* | 0.686*** | 0.895*** |
| | | (0.215) | (0.282) | (0.250) | (0.337) |
| Information Session | | | -0.401 | | -0.450 |
| × Use Pads Baseline | | | (0.439) | | (0.518) |
| Information Session with Stigma Module | | | | -0.669** | -0.696* |
| | | | | (0.292) | (0.386) |
| Information Session with Stigma Module | | | | | 0.044 |
| × Use Pads Baseline | | | | | (0.607) |
| Use Pads Baseline | 0.146 | 0.171 | 0.366 | 0.164 | 0.372 |
| | (0.222) | (0.221) | (0.315) | (0.220) | (0.316) |
| Age | 0.049* | 0.050* | 0.051* | 0.054** | 0.055** |
| | (0.028) | (0.027) | (0.028) | (0.027) | (0.028) |
| Years of Schooling | -0.020 | -0.024 | -0.024 | -0.026 | -0.026 |
| | (0.038) | (0.038) | (0.038) | (0.038) | (0.038) |
| Married | -0.138 | -0.109 | -0.103 | -0.111 | -0.103 |
| | (0.303) | (0.304) | (0.305) | (0.302) | (0.303) |
| Children | -0.014 | -0.009 | -0.033 | -0.036 | -0.062 |
| | (0.274) | (0.274) | (0.277) | (0.273) | (0.276) |
| Village Born | 0.930 | 0.940 | 0.895 | 1.001 | 0.950 |
| | (0.771) | (0.783) | (0.777) | (0.823) | (0.818) |
| Willingness to Pay | -0.031** | -0.032** | -0.031** | -0.032** | -0.031** |
| | (0.013) | (0.013) | (0.013) | (0.013) | (0.013) |
| Mean Collection Rate | 3.761 | | | | |
| Factory FE | Y | Y | Y | Y | Y |
| R-squared | 0.281 | 0.285 | 0.286 | 0.292 | 0.293 |
| Observations | 482 | 482 | 482 | 482 | 482 |

Notes: Table shows results from regressing a variable indicating the number of months a worker collected pads on a number of worker observables. Column 2 adds a dummy equal to one if the worker is also randomised into the information treatment arm, while column 3 interacts this with whether the worker used pads already at baseline. Column 4 controls for whether the worker is randomised into the information treatment with the additional stigma module, while column 5 interacts this again with baseline pad use. The sample includes all workers randomised into free pads collection treatment. Willingness to pay elicited through Becker-DeGroot-Marschak mechanism. Robust standard errors in parentheses: * < 0.1, ** < 0.05, *** < 0.01.

**Table 3.4:** Pad Use (Self Reported) at Endline Survey

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Dependent Variable: | | | Pad Use at Endline | | |
| Free Pads | 0.103*** | 0.100*** | 0.189*** | 0.220*** | 0.100*** |
| | (0.029) | (0.029) | (0.047) | (0.047) | (0.029) |
| Free Pads | | | -0.200*** | -0.211*** | |
| × Use Pads Baseline | | | (0.055) | (0.054) | |
| Information Session | 0.071** | 0.060* | 0.136*** | 0.127** | 0.085** |
| | (0.032) | (0.031) | (0.051) | (0.054) | (0.035) |
| Information Session | | | -0.167*** | -0.150** | |
| × Use Pads Baseline | | | (0.059) | (0.062) | |
| Free Pads & Information Session | 0.108*** | 0.105*** | 0.165*** | 0.191*** | 0.137*** |
| | (0.029) | (0.029) | (0.048) | (0.048) | (0.029) |
| Free Pads & Information Session | | | -0.138*** | -0.163*** | |
| × Use Pads Baseline | | | (0.052) | (0.054) | |
| Information Session with Stigma Module | | | | | -0.050 |
| | | | | | (0.040) |
| Free Pads & Information Session | | | | | -0.065** |
| with Stigma Module | | | | | (0.031) |
| Use Pads Baseline | | 0.112*** | 0.239*** | 0.232*** | 0.112*** |
| | | (0.019) | (0.044) | (0.048) | (0.019) |
| Mean Pad Use Rate at Endline, Control Group | 0.83 | | | | |
| Factory FE | Y | Y | Y | Y | Y |
| Worker Controls | | Y | Y | Y | Y |
| R-squared | 0.056 | 0.097 | 0.113 | 0.133 | 0.102 |
| Observations | 881 | 856 | 856 | 758 | 856 |
| Sample | | | | workers still at factory | |

Notes: Table shows results from regressing self-reported pad use at endline survey on indicator variables of the three main treatment groups (Free Pads, Information Session, and Free Pads & Information Session), plus interactions terms of the three variables with indicator variable whether worker reported to use pads already at baseline (column 3). Column 4 repeats column 3 on the sample of those workers still working at the factory at the time of the endline survey. Column 5 adds indicator variables whether the information sessions also included the "Stigma Module", showing the superior absorbing capacity of pads relative to traditionally used cloth. Workers Controls are worker age, marital status, parental status, years of schooling, baseline willingness to pay for pads, and whether born in village vs city. Robust standard errors in parentheses: * < 0.1, ** < 0.05, *** < 0.01.

**Table 3.5:** Main Results, HR Data based Outcomes

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | | | | Excluding Month of Unrest at 1 Factory | | | | |
| Dependent Variable: | Absent | Overtime | Earnings | Absent | Overtime | Earnings | Earnings | Stay at Factory |
| Free Pads | -0.115 | -0.783 | 164.696* | -0.133* | -0.806 | 165.986* | 127.146 | 0.028 |
| | (0.074) | (0.630) | (94.557) | (0.076) | (0.642) | (96.153) | (95.277) | (0.035) |
| Information Session | -0.151* | -0.715 | 99.244 | -0.170** | -0.727 | 101.871 | 50.744 | 0.052 |
| | (0.084) | (0.679) | (93.748) | (0.085) | (0.691) | (95.120) | (93.446) | (0.034) |
| Free Pads & Info Sessions | 0.034 | -0.942 | -31.546 | 0.027 | -0.964 | -32.105 | -27.422 | 0.038 |
| | (0.078) | (0.673) | (98.407) | (0.080) | (0.687) | (100.057) | (97.176) | (0.035) |
| Absent | | | | | | | -280.2*** | |
| | | | | | | | (11.68) | |
| Mean Control Group: | 0.640 | 29.23 | 9711.5 | 0.550 | 29.53 | 9710.5 | 9710.5 | 0.796 |
| Factory-Month FE | Y | Y | Y | Y | Y | Y | Y | |
| Worker FE | Y | Y | Y | Y | Y | Y | Y | |
| Factory FE | | | | | | | | Y |
| R-squared | 0.256 | 0.697 | 0.825 | 0.197 | 0.693 | 0.825 | 0.848 | 0.011 |
| Observations | 12,164 | 12,164 | 11,913 | 11,977 | 11,977 | 11,726 | 11,726 | 997 |

Notes: Table shows results from regressing outcome variables on the worker-month level from administrative HR data from the factories on indicator variables for the three main treatment groups (Free Pads, Information Session, and Free Pads & Information Session). Columns 1-7 show Difference in Difference regressions with worker and factory-month fixed effects. Treatment started in the middle of month at each factory (October 2018 at two factories, November 2018 at third), so data from this month is omitted. "Absent" is numbers of days worker was absent in the month, "Overtime" is number of monthly overtime hours (legally defined as any hour beyond 8 hours of work per day), while "Earnings" are full earnings in Bangladeshi Taka, including overtime pay and deductions for absent days. Column 8 shows regression on the worker level of a dummy indicating that worker still works at Factory around endline survey (April 2019) on the treatment dummies and factory fixed effects. "Mean Control Group" shows average of outcome variable among workers in control group in the post treatment start period. Standard errors clustered at the worker level in parentheses: * < 0.1, ** < 0.05, *** < 0.01.

**Table 3.6:** Willingness to Pay for Sanitary Pads

| | (1) | (2) | (3) |
|---|---|---|---|
| Dependent Variable: | Willingness to Pay (Endline) | | |
| Free Pads | 1.764* | 1.770* | 0.619 |
| | (1.011) | (1.012) | (1.373) |
| Free Pads × Use Pads Baseline | | | 2.369 |
| | | | (2.006) |
| Information Session | 1.179 | 0.691 | 1.319 |
| | (1.007) | (1.248) | (1.372) |
| Information Session with Stigma Module | | 0.967 | |
| | | (1.364) | |
| Information Session × Use Pads Baseline | | | -0.272 |
| | | | (1.992) |
| Free Pads & Information Session | -0.593 | -1.708 | -0.023 |
| | (1.040) | (1.260) | (1.343) |
| Free Pads & Information Session with Stigma Module | | 2.337 | |
| | | (1.451) | |
| Free Pads & Information Session × Use Pads Baseline | | | -1.344 |
| | | | (2.023) |
| Use Pads Baseline | 0.384 | 0.368 | 0.167 |
| | (0.740) | (0.741) | (1.445) |
| Mean Control Group: | 21.71 | | |
| Factory FE | Y | Y | Y |
| Surveyor FE | Y | Y | Y |
| Worker Controls | Y | Y | |
| R-squared | 0.166 | 0.170 | 0.170 |
| Observations | 758 | 758 | 758 |

Notes: Table shows results from regressing willingness to pay for sanitary pads (one pack of eight pads, same as distributed in free pads treatment) at endline survey on indicator variables of the three main treatment groups (Free Pads, Information Session, and Free Pads & Information Session), plus interactions terms of the three variables with indicator variable whether worker reported to use pads already at baseline (column 2). Column 3 adds indicator variables for whether the information session also included the "Stigma Module", showing the superior absorbing capacity of pads relative to traditionally used cloth. Willingness to pay elicited through Becker-DeGroot-Marschak mechanism. Worker Controls are worker age, marital status, parental status, years of schooling, and whether born in village vs city. Robust standard errors in parentheses: * $< 0.1$, ** $< 0.05$, *** $<$ 0.01.

**Table 3.7:** Well-being at Work during Menstruation, Self Reported (Endline Survey)

| Dep. Variable: | (1)<br>Less<br>Tired | (2)<br>Easier<br>to Reach<br>Target | (3)<br>More<br>Energetic | (4)<br>Feel<br>Shame | (5)<br>Worry<br>Leakage | (6)<br>Worry<br>Odour | (7)<br>Feel<br>Alone | (8)<br>Feel<br>Irritated | (9)<br>PCA<br>Work<br>Ease | (10)<br>PCA<br>Psych.<br>Burden |
|---|---|---|---|---|---|---|---|---|---|---|
| Free Pads | 0.001 | -0.185** | 0.116 | -0.085 | -0.061 | 0.003 | 0.041 | -0.026 | -0.055 | -0.045 |
| | (0.090) | (0.089) | (0.083) | (0.099) | (0.095) | (0.087) | (0.083) | (0.104) | (0.112) | (0.112) |
| Info Session | 0.045 | -0.000 | 0.213*** | -0.055 | 0.099 | 0.016 | -0.053 | -0.010 | 0.084 | -0.001 |
| | (0.089) | (0.089) | (0.082) | (0.098) | (0.094) | (0.086) | (0.082) | (0.103) | (0.112) | (0.112) |
| Free Pads<br>& Info Session | 0.056<br>(0.090) | -0.048<br>(0.090) | 0.129<br>(0.083) | -0.077<br>(0.100) | -0.052<br>(0.095) | -0.041<br>(0.087) | 0.093<br>(0.083) | 0.056<br>(0.104) | 0.064<br>(0.113) | -0.047<br>(0.118) |
| Factory FE | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Worker Controls | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Surveyor FE | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| R-squared | 0.203 | 0.336 | 0.449 | 0.246 | 0.375 | 0.442 | 0.360 | 0.275 | 0.371 | 0.450 |
| Observations | 846 | 818 | 846 | 845 | 846 | 846 | 846 | 846 | 818 | 845 |

Notes: Table shows results from regressing self-reported well-being at work along eight dimensions at endline survey on indicator variables of the three main treatment groups (Free Pads, Information Session, and Free Pads & Information Session). Worker Controls are worker age, marital status, parental status, years of schooling, and whether born in village vs city. PCA Work Ease is first principal component of outcomes of columns 1, 2, 3, 8, while PCA Psych. Burden is first principal component of outcomes from columns 4-7. Robust standard errors in parentheses: * < 0.1, ** < 0.05, *** < 0.01.

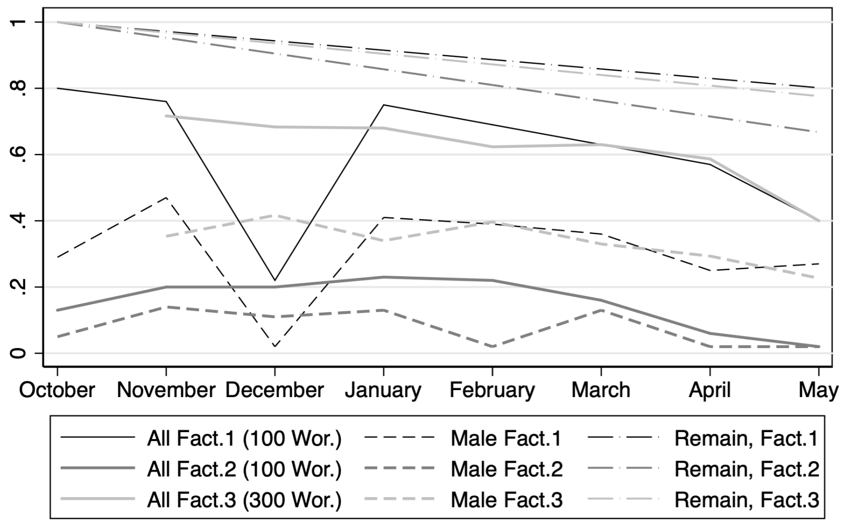
**Table 3.8:** Mobility, Behaviour and Social Norms beyond Work-Place

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| Dep. Variable: | Cook | Eat with Husband | Eat with Others | Religious Activity | Go to Market | Visit Sick | Visit Newborn | Dry Cloth Outside | Walk Distance | Take Bus |
| **Panel 1: Self Reported Mobility** | | | | | | | | | | |
| Free Pads | 0.015 | 0.123 | | -0.146** | -0.001 | 0.009 | 0.010 | 0.037 | 0.054 | -0.012 |
| | (0.084) | (0.083) | | (0.065) | (0.099) | (0.101) | (0.114) | (0.071) | (0.087) | (0.084) |
| Info Session | 0.107 | 0.188** | | -0.180*** | 0.104 | 0.074 | 0.045 | 0.135* | 0.042 | 0.049 |
| | (0.083) | (0.082) | | (0.065) | (0.099) | (0.100) | (0.113) | (0.071) | (0.086) | (0.083) |
| Free Pads | 0.074 | 0.163** | | -0.127* | 0.080 | 0.059 | 0.151 | 0.142** | 0.004 | 0.052 |
| & Info Session | (0.084) | (0.083) | | (0.065) | (0.100) | (0.101) | (0.114) | (0.072) | (0.087) | (0.084) |
| Mean Control Group: | 2.50 | 2.40 | | 0.30 | 1.88 | 1.72 | 1.43 | 0.18 | 1.99 | 2.31 |
| Observations | 851 | 851 | | 851 | 850 | 851 | 851 | 851 | 849 | 849 |
| **Panel 2: Injunctive Norms** | | | | | | | | | | |
| Free Pads | -0.010 | -0.001 | 0.027 | 0.050* | -0.030 | 0.109 | 0.158* | 0.092** | | |
| | (0.086) | (0.083) | (0.105) | (0.026) | (0.083) | (0.090) | (0.096) | (0.047) | | |
| Info Session | 0.037 | 0.097 | 0.156 | 0.028 | 0.057 | 0.116 | 0.123 | 0.277*** | | |
| | (0.085) | (0.080) | (0.102) | (0.019) | (0.081) | (0.091) | (0.097) | (0.061) | | |
| Free Pads | 0.094 | 0.103 | 0.225** | 0.055** | -0.048 | -0.026 | 0.118 | 0.220*** | | |
| & Info Session | (0.086) | (0.080) | (0.101) | (0.025) | (0.082) | (0.088) | (0.098) | (0.057) | | |
| Mean Control Group: | 2.44 | 2.47 | 1.71 | 0.00 | 1.78 | 1.82 | 1.44 | 0.08 | | |
| Observations | 844 | 844 | 844 | 845 | 845 | 844 | 844 | 845 | | |
| **Panel 3: Descriptive Norms** | | | | | | | | | | |
| Free Pads | -0.029 | 0.004 | 0.033 | 0.029 | 0.005 | 0.005 | 0.023 | 0.037 | | |
| | (0.053) | (0.059) | (0.081) | (0.020) | (0.065) | (0.070) | (0.083) | (0.048) | | |
| Info Session | -0.080 | -0.004 | 0.023 | 0.004 | 0.119* | 0.070 | 0.092 | 0.182*** | | |
| | (0.050) | (0.059) | (0.080) | (0.003) | (0.063) | (0.072) | (0.087) | (0.063) | | |
| Free Pads | 0.058 | 0.125** | 0.191** | 0.000 | 0.051 | -0.046 | 0.021 | 0.165*** | | |
| & Info Session | (0.045) | (0.051) | (0.075) | (0.002) | (0.067) | (0.074) | (0.087) | (0.058) | | |
| Mean Control Group: | 2.79 | 2.72 | 2.26 | 0.00 | 2.08 | 2.21 | 1.97 | 0.11 | | |
| Observations | 758 | 758 | 758 | 758 | 758 | 758 | 758 | 758 | | |
| Factory FE | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Surveyor FE | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Worker Controls | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |

Notes: Table shows results from regressing self-reported behaviours (Panel 1), or perceived strength of restrictive norms around these behaviours (Panel 2 + 3) at endline survey on indicator variables of the three main treatment groups (Free Pads, Information Session, and Free Pads & Information Session). Outcomes measured on four-item Likert scale 0-3, with higher values indicating higher likelihood in engaging in behaviour during period (Panel 1), or less restrictive perceived norms on that behaviour during periods. "Injunctive" norms (Panel 2) describe what worker thinks people "should" do, while "Descriptive" norms (Panel 3) describe what worker thinks most people actually do. Responses in Panels 2 and 3 incentivised with small bonus if worker answer matched modal answer among workers. "Mean Control Group" indicates mean answer among control workers at endline on 0-3 Likert scale. Worker Controls are worker age, marital status, parental status, years of schooling, and whether born in village vs city. Robust standard errors in parentheses: * < 0.1, ** < 0.05, *** < 0.01.

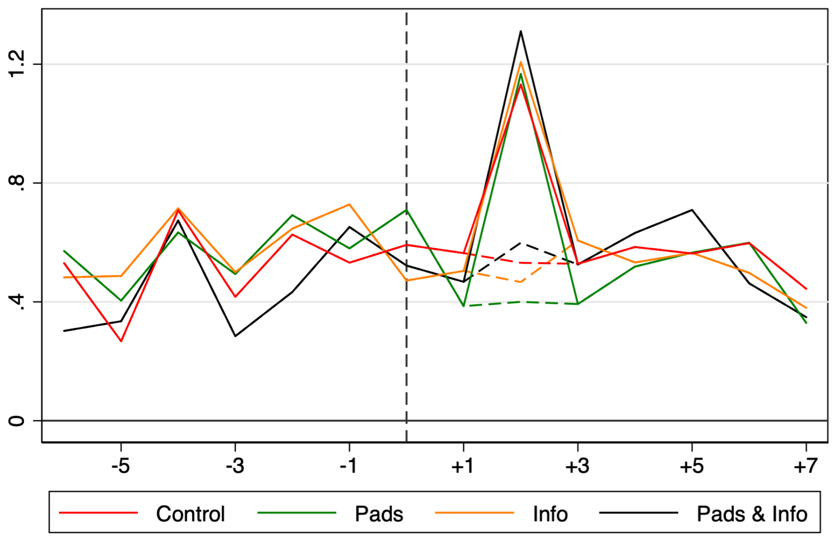
## 3.8 Figures

**Figure 3.1:** Share of Workers Collecting Pads Each Month



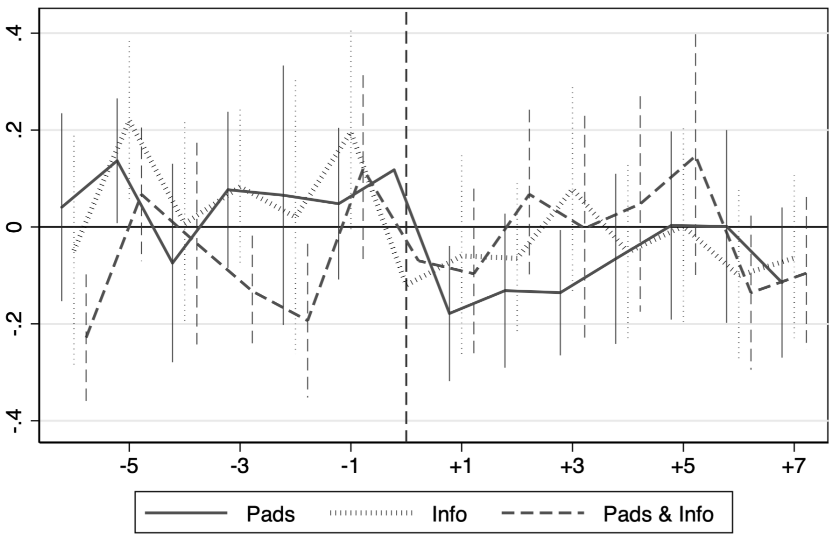

Notes: Figure shows month-by-month the share of workers randomised into receiving free pads who collected them from the distribution workers at the three factories. The dashed lines show the share of workers each month who collected them from the male as opposed to the female distribution worker. The dashed-dotted lines show the share of the workers still working at the factory at that month.

**Figure 3.2:** Absent Days: Time Series of Average Worker Absenteeism



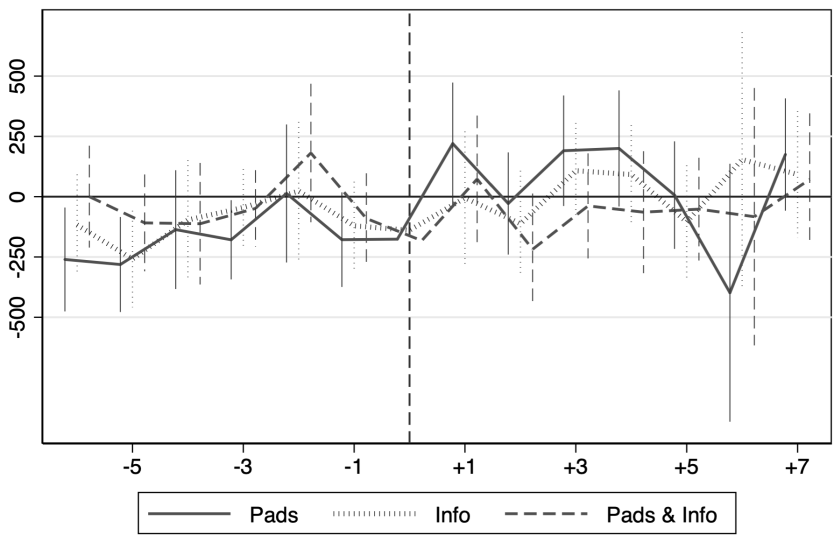

Notes: Graph shows the month-by-month time series of average worker absenteeism (number of days worker was absent per month) in each of the three main treatment groups and the control group in the month prior and after the information sessions and start of the distribution of pads. Dashed lines show means when dropping the 200 workers from factory with unrest for December 2018.

**Figure 3.3:** Absent Days: Deviation of Average Worker Absenteeism




Notes: Graph shows the month-by-month time series of deviation of average worker absenteeism (number of days worker was absent per month) of each of the three main treatment groups from the control group, in the month prior and after the information sessions and start of the distribution of pads. Spikes show 95% confidence intervals. Without data from 200 workers for December 2018 from factory with unrest.

**Figure 3.4:** Earnings: Deviation of Average Worker Pay




Notes: Graph shows the month-by-month time series of deviation of average worker pay (including overtime pay and deductions for absenteeism) of each of the three main treatment groups from the control group, in the month prior and after the information sessions and start of the distribution of pads. Earning in Bangladeshi Taka (BDT). Spikes show 95% confidence intervals. Without data from 200 workers for December 2018 from factory with unrest.

## 3.9 Appendix A: Additional Tables

**Table 3.9:** Pad Use at Endline with four-item Likert Scale (Ordered Probit)

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Dependent Variable: | | | Pad Use at Endline | | |
| Free Pads | 0.523*** | 0.506*** | 0.799*** | 0.999*** | 0.507*** |
| | (0.157) | (0.164) | (0.203) | (0.251) | (0.164) |
| Free Pads × Use Pads Baseline | | | -1.043*** | -1.054** | |
| | | | (0.376) | (0.425) | |
| Information Session | 0.258* | 0.150 | 0.420** | 0.473** | 0.219 |
| | (0.144) | (0.149) | (0.185) | (0.197) | (0.181) |
| Information Session × Use Pads Baseline | | | -0.896*** | -0.884** | |
| | | | (0.338) | (0.353) | |
| Free Pads & Information Session | 0.543*** | 0.512*** | 0.600*** | 0.840*** | 0.699*** |
| | (0.164) | (0.168) | (0.194) | (0.224) | (0.214) |
| Free Pads & Information Session × Use Pads Baseline | | | -0.334 | 3.209*** | |
| | | | (0.434) | (0.374) | |
| Information Sessions with Stigma Module | | | | | -0.131 |
| | | | | | (0.224) |
| Free Pads & Information Sessions with Stigma Module | | | | | -0.349 |
| | | | | | (0.266) |
| Use Pads Baseline | | 0.710*** | 1.307*** | 1.242*** | 0.709*** |
| | | (0.131) | (0.269) | (0.275) | (0.131) |
| Mean Pad Use Rate at Endline, Control Group | 2.48 | | | | |
| Factory FE | Y | Y | Y | Y | Y |
| Worker Controls | | Y | Y | Y | Y |
| R-squared | 0.056 | 0.097 | 0.113 | 0.133 | 0.102 |
| Observations | 881 | 856 | 856 | 758 | 856 |
| Sample | | | | workers still at factory | |

Notes: Table replicates Table 3.4, but using the raw four-item pad adoption at endline variable as outcome, coded as 0 "Never", 1 "Sometimes", 2 "Often", and 3 "Always". All specifications estimated by ordered probit. Worker Controls are worker age, marital status, parental status, years of schooling, baseline willingness to pay for pads, and whether born in village vs city. Robust standard errors in parentheses: * < 0.1, ** < 0.05, *** < 0.01.

**Table 3.10:** HR Data based outcomes, with Stigma Module in Information Session

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | | | | Excluding Month of Unrest at 1 Factory | | | | |
| Dependent Variable: | Absent | Overtime | Earnings | Absent | Overtime | Earnings | Earnings | Stay at Factory |
| Free Pads | -0.115 | -0.783 | 164.688* | -0.133* | -0.806 | 165.978* | 127.151 | 0.028 |
| | (0.074) | (0.630) | (94.565) | (0.076) | (0.642) | (96.162) | (95.286) | (0.035) |
| Information Session | -0.189* | -1.339* | 85.880 | -0.206** | -1.349* | 87.880 | 30.402 | 0.052 |
| | (0.102) | (0.766) | (112.989) | (0.104) | (0.782) | (114.806) | (112.427) | (0.041) |
| Free Pads & Info Session | -0.053 | -0.538 | 9.807 | -0.057 | -0.543 | 12.958 | -3.959 | 0.066 |
| | (0.092) | (0.839) | (113.284) | (0.094) | (0.857) | (115.377) | (113.017) | (0.040) |
| Information Session | 0.076 | 1.238 | 26.722 | 0.071 | 1.235 | 27.955 | 40.650 | -0.000 |
| with Stigma Module | (0.125) | (1.008) | (126.232) | (0.127) | (1.027) | (128.104) | (123.525) | (0.046) |
| Free Pads & Info Session | 0.177 | -0.816 | -83.319 | 0.170 | -0.850 | -90.626 | -47.188 | -0.055 |
| with Stigma Module | (0.109) | (0.994) | (139.531) | (0.112) | (1.015) | (142.114) | (135.076) | (0.047) |
| Absent | | | | | | | -280.106*** | |
| | | | | | | | (11.686) | |
| Mean Control Group: | 0.640 | 29.23 | 9711.5 | 0.550 | 29.53 | 9710.5 | 9710.5 | 0.796 |
| Factory-Month FE | Y | Y | Y | Y | Y | Y | Y | |
| Worker FE | Y | Y | Y | Y | Y | Y | Y | |
| Factory FE | | | | | | | | Y |
| R-squared | 0.256 | 0.697 | 0.825 | 0.197 | 0.694 | 0.825 | 0.848 | 0.013 |
| Observations | 12,164 | 12,164 | 11,913 | 11,977 | 11,977 | 11,726 | 11,726 | 997 |

Notes: Table replicates Table 3.5, but adding two independent variables. The first is an indicator variable for those workers that were randomised into information sessions that also included the stigma module, but not into access to free pads. The second is an indicator variable for those workers who were randomised into access to free pads and the information session with the stigma module. Both variables interacted with post-treatment start dummies. The definitions of the variables "Information Session" and "Free Pads & Info Session" remains unchanged from Table 3.5. Thus the coefficients on the two new variables show the difference in average outcomes between those workers attending information sessions with stigma modules, and those who are randomised into the same treatments ("Information Session" and "Free Pads & Info Session"), just without the stigma module. * < 0.1, ** < 0.05, *** < 0.01.

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