Rural infrastructure for inclusive rural transformation: Case studies on roads, markets and irrigation from Bangladesh and the Philippines

Daniel Higgins

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Daniel Higgins
2021

Propositions

1. Improved rural infrastructure - under the right conditions - is an important tool to promote inclusive rural transformation.
   (this thesis)
2. Improvements in crop yields is just one of several indicators of a successful rural development project.
   (this thesis)
3. When women's rights are restricted, promoting gender equity requires more than just improving infrastructure.
4. It is possible to conduct robust impact evaluations using only ex-post data.
5. External PhD programmes can offer a valuable alternative for those who want to continue to work while completing their studies.
6. Working towards a goal is often more satisfying than achieving it.

Proposition belonging to the thesis, entitled

Rural infrastructure for inclusive rural transformation: Case studies on roads, markets and irrigation from Bangladesh and the Philippines

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Rural infrastructure for inclusive rural transformation: Case studies on roads, markets and irrigation from Bangladesh and the Philippines

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Thesis

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Contents

List of abbreviations

ATE	Average Treatment Effect
ATET	Average Treatment Effect on the Treated
CCRIP	Coastal Climate Resilient Infrastructure Project
CEM	Coarsened Exact Matching
CIS	Communal Irrigation System
IA	Irrigators' Association
IFAD	International Fund for Agricultural Development
IPTW	Inverse Probability of Treatment Weighting
IPWRA	Inverse Probability Weighted Regression Adjustment
IRPEP	Irrigated Rice Production Enhancement Project
FFS	Farmer Field Schools
FGD	Focus Group Discussion
FIES	Food Insecurity Experience Scale
HDDS	Household Dietary Diversity Scale
KII	Key Informant Interview
LCS	Labour Contracting Societies
MF	Deterministic Meta-Frontier
MMC	Market Management Committee
MTE	Meta-Technical Efficiency
PSM	Propensity Score Matching
SC-SPF	Selectivity Corrected Stochastic Production Frontier
SDGs	Sustainable Development Goals
SMD	Standardised Mean Difference
SPF	Stochastic Production Frontier
SMF	Stochastic Meta-Frontier
TE	Technical Efficiency
TGR	Technology Gap Ratio
VR	Variance Ratio

Chapter 1

Introduction

1.1 Inclusive rural transformation and the Sustainable Development Goals (SDGs)

Many of the goals outlined in the 2030 Agenda for Sustainable Development will not be achieved unless additional measures are taken to accelerate progress (UN, 2019). These measures must arrest the slowdown in extreme poverty reduction, stubbornly high rates of gender inequality, uneven infrastructure development, and the alarming rise in global hunger, economic inequality and land degradation (FAO, 2018a; UN, 2019). In rural areas, a range of factors have hindered progress, including frequent climatic shocks and changing rainfall patterns, conflict and displacement, youth unemployment, population growth and land stress, and limited access to information, inputs, markets and value chains (World Bank, 2008a; Wheeler & Von Braun, 2013; Pinstrup-Andersen, 2015; IFAD, 2016a). Identifying effective ways to address these issues in rural areas is key to stimulating inclusive transformation of rural economies in developing countries, which in-turn is central to achieving the SDGs (IFAD, 2018a).

As economies develop, they invariably follow a process of structural transformation that sees agriculture constitute a declining share of national income, moving instead towards integrated and high-productivity economies based primarily on industry and services (McMillan and Rodrik, 2011; Gollin, 2014). The speed and form of this structural transformation process is shaped significantly by the economic and social changes that occur in rural areas (Timmer, 2009; Losch et al., 2011; IFAD, 2016a). The reduced share of agriculture in national incomes is a result of rural households shifting into more efficient on- and off-farm activities that allow labour to be released into the manufacturing and services sectors, thus driving the industrialisation and urbanisation characteristic of more developed economies (Haggblade et al., 2007; IFAD, 2016a).

The integration of rural households into consolidated value chains also facilitates trade, further fuelling the growth of towns and cities and attracting outside investment, and as rural incomes increase, the structural transformation process is further accelerated through greater spending, investment, taxes and savings (Timmer, 2009; Berdegué et al., 2013).

Rural transformation refers to the transition of a subsistence-based, low productivity, labour-intensive rural economy to one that is modernised and more capital-intensive, with higher productivity, greater off-farm income generation, and more integration with national and international value chains (Berdegué et al., 2013). Rural transformation that is inclusive ensures that no one is left behind as part of this process (IFAD, 2016a).

Rural transformation as a concept has its roots in Farming Systems Research, the Sustainable Rural Livelihoods framework and the Integrated Rural Development approach (Ruttan, 1984; Carney, 1998; Collinson, 2000; Berdegue et al., 2013). These approaches have been developed over the past thirty-five years based on the notion that rural development is not based solely on Green Revolution-style agricultural modernisation, but on the all-round improvement of rural livelihoods and the efficient reallocation of labour across sectors (World Bank, 2008a; Berdegue et al., 2013). As climate change has begun to threaten farming activities in developing countries, making off-farm opportunities more important, the relevance of such wider approaches to rural development that consider both on and off-farm activities has heightened further (Rigg et al., 2016). The inclusive rural transformation concept builds on these approaches by emphasising the links between rural change and wider structural transformation and brings to the fore the need for inclusivity of all groups.

Rural transformation in a given area is comprised of multiple interlinked processes. Based on the experience of most developed countries, rural transformation is usually sparked by improvements in agricultural productivity, which helps to activate labour re-allocation to other sectors and activities (Timmer, 2009). Greater farm yields also provide more marketable surplus, the income from which can then be re-invested in the further improvement and modernisation of on-farm activities, and for advancing into lucrative off-farm income generating activities, thus stimulating the growth of off-farm sectors and diversification of the economy. Both a condition and an outcome of this re-investment effect is an increase in households' access to markets and physical assets. As part of a snowball effect, more off-farm income can in turn complement farming activities by easing binding capital constraints (Babatunde and Qaim, 2010).

Changes in risk attitudes also play an important role. With the safety net that robust and reliable farm productivity and income provides—plus the increase in assets and resilience—some of the constraints that shape rural households' risk attitudes can be reduced. This could make them more willing to adopt new technologies and innovations or to shift towards the more lucrative activities that are characteristic of modernised rural economies (Feder et al., 1985; Rosenzweig & Binswanger, 1993; Boto et al., 2011; Freguin-Gresh et al., 2012).

Rising agricultural productivity and income should also lead to an increase in food security and nutrition, unless there are food supply constraints (Kennedy and Bouis, 1993; Bashir and Schilizzi, 2013). In-turn, better food security and nutrition can contribute to the transformation process by ensuring households have the long-term capacity to engage in productive livelihood activities on and off the farm (Strauss, 1986; FAO, 2014; Tiwasing et al., 2019).

Rising incomes can also allow rural households to afford more training and extension services and to send their children to school. Children's educational enrolment can also be improved if more efficient livelihood activities helps to reduce the need for child labour (FAO, 2012a). As with food security and nutrition, better education can feed back into the transformation process by enhancing long-term livelihood capacities, reducing risk aversion, and increasing technology adoption (Lockheed et al. 1980; Phillips, 1994; Knight et al. 2010; Dadzie and Acquah, 2012; Paltasingh and Goyari, 2018).

Changes in access to social capital and networks is another facilitator and outcome of rural transformation. Social capital is defined as the capacity of a household to draw upon the power of collective action to increase their wellbeing or protect against shocks (Woolcock & Narayan, 2000). More efficient livelihoods achieved through the transformation process, along with local economic development and institution strengthening, can help to improve social capital by allowing more time and opportunities for collaborative activities, and by increasing trust within communities (Narayan and Pritchett, 1999; Asadullah, 2017). In-turn, stronger social capital can complement the transformation process by improving productivity and livelihood capacity through sharing of information and risk, increased trust, and reduced transaction costs (Fafchamps and Minten, 2002; Katungi, 2007; Liverpool and Winter-Nelson, 2010).

Rural transformation that is inclusive requires that opportunities to improve upon the components outlined above are available to all members of the rural population (IFAD, 2016a; FAO, 2017). Inequality in any of these areas can hinder efficient allocation of labour and other resources in the rural economy, potentially forcing disadvantaged households into undesirable activities, or causing mass migration to urban areas to the detriment of both the rural and urban economy and to national poverty levels (Berdegué et al., 2013; Christiaensen and Todo, 2013; IFAD, 2016a). This is detrimental to individual households and can slow down the wider transformation process. For example, concentrated land ownership could mean that gains from agricultural surplus are less likely to be spent and invested locally (Berdegué et al., 2013), while Zhang and Wan (2006) find that, between 1988-1999, economic growth in China was curtailed because many rural producers were unable to advance into the off-farm sector, having lacked the market access and financial, physical and human capital to do so.

The inclusion of women is particularly salient, given the importance of gender equality to the transformation process, and the multiple social and economic barriers that women face to their productive participation in the economy (Lele, 1986; Deere & Doss 2006; Meinzen-Dick et al. 2014). Rural transformation has the potential to increase gender equality and women's empowerment, for example, by increasing their income generating opportunities, or by increasing agricultural efficiency and thus reducing their need to tend the family farm. However, much of the evidence suggests that adoption of new technologies and greater farm output may instead increase women's labour requirements, and women are also at risk through the transformation process of being left to tend the family farm or focusing on subsistence crops whilst male household members engage in new higher-value activities or migrate to urban centres (Doss, 2001; Slavchevska et al., 2016). As well as being detrimental to women's wellbeing, such exclusion can seriously hinder the transformation process, as limiting women's economic opportunities will restrict efficient allocation of labour. In addition, some research suggests that offering women greater decision making power in the household can lead to better management of the household budget, which could lead to more effective investments in economic activities, better nutrition and more education (World Bank, 2001; FAO, 2011a; Duflo, 2012).

Based on this outline of the rural transformation process, it is clear that stimulating faster and more inclusive rural transformation in developing countries can contribute to the SDGs in many ways. Modernised production and enhanced off-farm activities are important determinants of productivity and income, and are thus key to achieving zero poverty and hunger (Goals 1 and 2). Higher incomes and more stable and resilient livelihoods should also promote greater investment in health and education (Goals 3 and 4), as well as in improved industry, innovation and infrastructure (Goal 9). A fully inclusive transformation process will increase equality (Goal 10), particularly for women (Goal 5). As rural economies become more modernised, efficiency is expected to improve, especially in agriculture, and time horizons for investments are expected to lengthen, meaning that the rural transformation process can also help to ensure sustainable production patterns (Goal 12) and sustainable use of land and other natural resources (Goal 15). More efficient, diversified and sustainable livelihoods could also facilitate climate change mitigation and adaptation (Goal 13).

In recognition of these linkages with the SDGs, accelerating inclusive rural transformation has become a policy priority amongst rural development institutions, as highlighted by two recent flagship publications in the rural development community: the Rural Development Report 2016 (entitled "*Fostering inclusive rural transformation*") by the International Fund for Agricultural Development (IFAD), and the State of Food and Agriculture Report 2017 (entitled "*Leveraging Food Systems for Inclusive Rural Transformations*") by the United Nations' Food and Agriculture Organisation (IFAD, 2016a; FAO, 2017). Through the insights provided by this thesis, a better understanding of inclusive rural transformation pathways can help to guide this growing policy-focus and investment.

1.2 Mission statement

In this thesis, we analyse the ways that improved rural infrastructure can impact inclusive rural transformation, represented by changes in farm and off-farm livelihoods, assets, food security, nutrition, resilience, social capital, education, and gender equality. While plausible, many of the potential links between rural infrastructure and these indicators lack consistent supporting evidence. Empirically testing these links will help to fill these evidence gaps, and in-turn improve our understanding of the impact pathways of rural infrastructure projects and the influence of various contextual factors. Ongoing investments aiming to stimulate inclusive rural transformation, as a means of contributing to the SDGs, can then be made more effective, equitable and efficient thanks to these insights. Our analyses focus on two large-scale rural infrastructure projects in the Philippines and Bangladesh, two countries that are at risk of failing to meet several of the SDGs (Sachs et al., 2020).

1.3 Case study contexts

Along with most countries in South Asia, there has been notable progress in both structural and rural transformation in Bangladesh and the Philippines over the past twenty years. Between 2000-2018, the value added from agriculture as a proportion of GDP fell from 23 to 13 per cent in Bangladesh, and from 14 to 9 per cent in the Philippines (World Bank, 2019). In the same period, the proportion of agricultural employment as a proportion of total employment shifted from 61 to 31 per cent for men and from 79 to 59 per cent for women in Bangladesh, and from

45 to 31 per cent for men and 24 to 14 per cent for women in the Philippines (World Bank, 2019). A key indicator of rural transformation is agricultural labour productivity (measured by value added per worker), which, between 2000-2018, increased from $445 to $989 in Bangladesh and from $1,894 to $3,235 in the Philippines—however the level for Bangladesh remains well below the average for the South Asia region ($1,756) and the level for the Philippines is below that for the industry and services sectors in the country (NEDA, 2017a; World Bank, 2019).

Smallholder farmers comprise the majority of the rural population in both countries, and according to both countries' national development plans, further rural and structural transformation progress is being hindered by the challenges faced by this group (GED, 2015; NEDA, 2017a). In Bangladesh, almost all rural households are involved in some form of agriculture and the average farm size amongst them is just 1.1 hectares, while in the Philippines, 99 per cent of the country's farms are family-owned and 88 per cent of landholdings are smaller than three hectares (PSA, 2015; BBS, 2018). In both countries, smallholder farmers and their households are predominantly poor, and have limited access to land, assets, markets, infrastructure, extension services, credit, varied diets, schools, and healthcare, and are highly vulnerable to climatic shocks (Anderson et al., 2016; Rigg et al., 2016). These barriers hinder them from contributing to and benefitting from the rural transformation process and has left both countries off-course in meeting several of the SDGs including zero hunger (Goal 2), good health and wellbeing (Goal 3), gender equality (Goal 5), and economic equality (Goal 10) (Sachs et al., 2020).

The issue of equality for rural women in smallholder households is a particular issue in both countries. In the Philippines, according to a recent gender assessment of the rural sector by FAO

(2018b), women face considerable cultural barriers to work—such as the unequal burden of unpaid care work in the household and community—and are more likely to suffer from malnutrition. Another survey found that less than ten per cent of rural female respondents had access to production capital (PAKISAMA, 2015). In Bangladesh the situation is seemingly even more severe, especially in terms of the restrictive cultural norms imposed upon women's mobility and activities in poor rural households (Ahmed and Nahiduzzaman, 2016; Paul, 2016; Ambler et al., 2017). Reflecting this, unemployment among rural women stands at 58 per cent, and as noted above, only one third of women's employment is outside of the agriculture sector (Rahman and Islam, 2019; World Bank, 2019). Within the agriculture sector, agricultural wage rates are 38 per cent higher for men than women (Wiggins and Keats, 2014).

The national development plans of both countries identify improvements in rural infrastructure as a key tool for solving the barriers faced by smallholder farmers, and thus driving inclusive rural transformation and economic growth (GED, 2015; NEDA, 2017a). In Bangladesh, policy and investment has focused primarily on the improvement of rural roads, as well as building and improving local markets used by smallholders to buy inputs and sell their produce (GED, 2015). This focus is also shared by development agencies, with the Asian Development Bank recently announcing a new $100 million project to improve rural road networks, which builds upon a $200 million project approved in 2018 (ADB, 2020). In the Philippines, given the predominance of rice farming amongst smallholders, the focus has been on improving irrigation coverage for this group (NEDA, 2017a; Delos Reyes and Schultz, 2018). In 2019, for instance, the National Irrigation Authority increased irrigation coverage by 33,407 hectares and repaired systems covering a further 9,954 hectares, using its annual budget of $800 million (NIA, 2020).

In Chapters 2 and 3 of this thesis we focus on the impacts of the Irrigated Rice Production Enhancement Project (IRPEP) in the Philippines. This was a $25 million project implemented in three of the country's poorest regions that targeted 14,000 smallholder rice farming households with new and improved canal irrigation systems. It also provided complementary support by strengthening the capacity of Irrigators Associations (IAs) tasked with managing the systems, and offering training through Farmer Field Schools (FFS). Chapters 4 and 5 focus on the impact of the Coastal Climate Resilient Infrastructure Project (CCRIP) in southwest Bangladesh, a $150 million project that targeted 3.5 million small-scale producers by building climate resilient roads and markets in remote areas affected by climatic shocks. As with IRPEP, CCRIP also complemented this support by providing capacity building training to local MMCs.

Both of the case study projects were financed by IFAD, a United Nations agency with a mandate to support the livelihoods of small-scale producers in rural areas in developing countries. With contributions from member states, the Fund designs projects in collaboration with recipient governments, which the government then implements with financing from the Fund in the form of grants or loans (both concessional and non-concessional). In its current financing window (2019-2021), the Fund has a portfolio of investments totalling $3.5 billion, targeted at supporting the achievement of the SDGs by increasing the food security, market participation, and climate change mitigation and adaptation of the rural poor (IFAD, 2016b).

1.4 Theory of change

Both projects aim to achieve their objectives mainly by reducing the barriers and improving the conditions for better agricultural production among smallholders. In the case of CCRIP in Bangladesh, climate resilient road and market infrastructure is expected to help to improve and modernise smallholder production by reducing transaction costs for accessing inputs, and in the Philippines, better irrigation systems are expected to accelerate crop growth and avoid disruption caused by unreliable rainfall (BUET, 2018; Delos Reyes and Schultz, 2018). With more reliable production, combined with more reliable sales locations in Bangladesh, beneficiaries are expected to be encouraged to invest more in agricultural production, be less risk averse, and adopt new technologies, cash crops, practices and seeds. In the Philippines, more efficient production thanks to better irrigation is also expected to drive labour re-allocation. Better market access through improved markets and roads in Bangladesh is also intended to help to connect smallholder producers to existing value chains and help to develop new ones, and can provide opportunities for households to re-allocate labour in line with their comparative advantage (Swinnen, 2007; Reardon, 2015; Bradbury et al., 2017). The higher incomes produced by these linkages would then ideally also be invested into assets, better diets, and education. Nutrition and education could also be improved if the roads help to improve access to schools, food, and health centers.

In Bangladesh, social capital among smallholders could also be improved if better roads and markets allow smallholder households to be better connected and to access well-attended meeting points (Bradbury, 2006). In the Philippines, irrigation schemes that are user-managed—a common aspect of small-scale irrigation projects in the country—can increase trust, social cohesion and mutual support, as well as provide opportunities for households to increase their involvement in collective activities in their community (Kähkönen, 1999; Uphoff and Wijayaratna, 2000). In both countries, increased incomes and labour productivity through the above linkages can also allow households to dedicate more time and resources to collective activities and building social networks, which can then feed back into income generation (Narayan and Pritchett, 1999).

Another reason that rural infrastructure is being used to drive inclusive rural transformation in Bangladesh and the Philippines is its potential to build the resilience of smallholders' livelihoods to climatic shocks. The two countries are among the worst affected by these shocks, which include droughts, floods, storms, typhoons, cyclones, changing rainfall patterns, and rising temperatures and sea levels (Parvin and Johnson, 2015; Maplecroft, 2019). Such shocks threaten the inclusive rural transformation process in several ways. First they can hinder agricultural production by damaging produce and assets (including land, machinery and storage facilities) and disrupting growing seasons (Morton, 2007). Nelson et al. (2014) estimate, for instance, that global yields will have reduced by 17 per cent by 2050 due to the weather effects caused by climate change. Damage to assets and infrastructure can also mean that households do not have the resources to shift into more lucrative livelihood activities (IPCC, 2014). By reducing the resilience and stability of their livelihoods, and potentially increasing their risk aversion, these effects—which disproportionately affect smallholders and other vulnerable groups—can also serve to disincentivise investment in new livelihood activities and practices that would advance the transformation process (Mirza, 2003; Béné et al, 2014; Anand and Khetarpal, 2015; MacMahon, 2017).

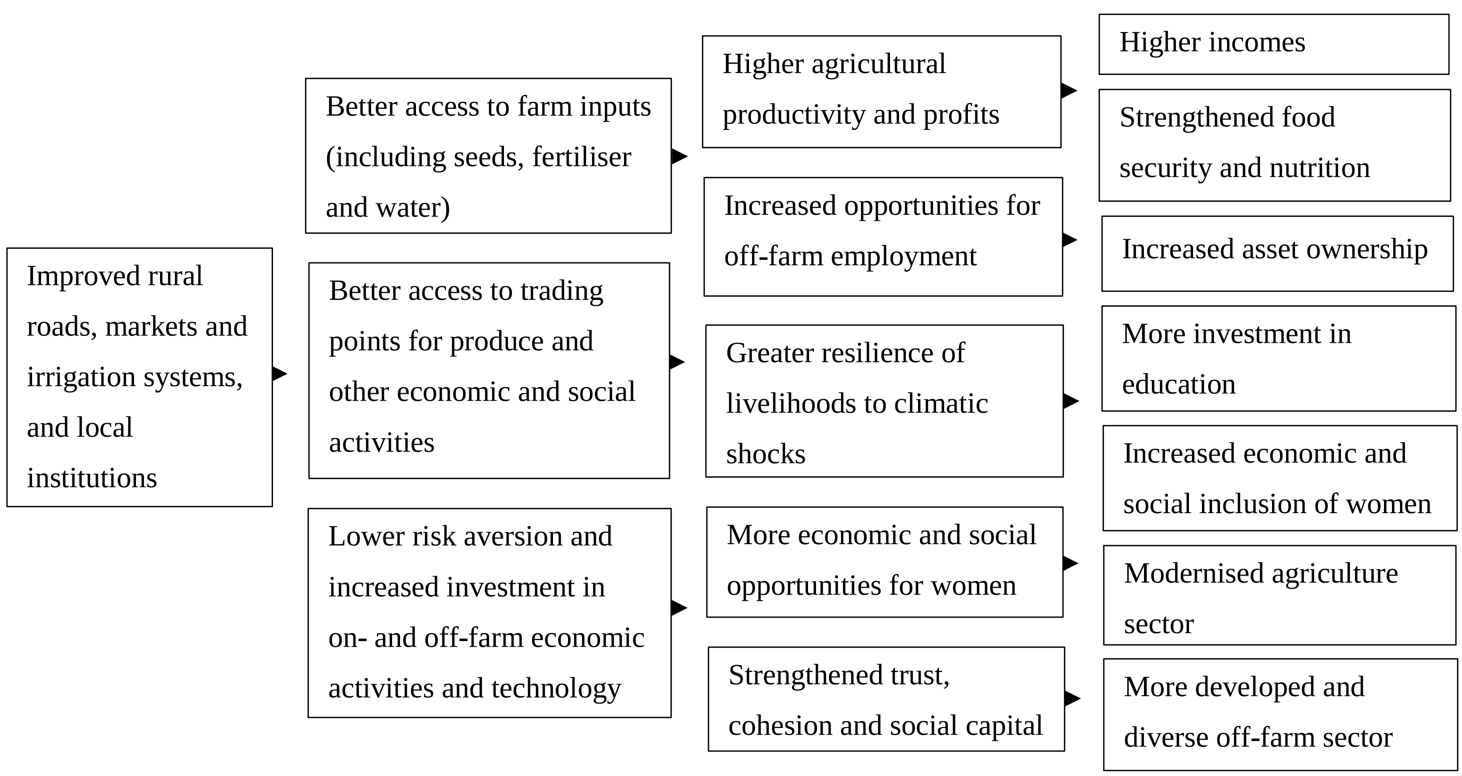
The two case study projects aim to mitigate the threats of climatic shocks in a number of ways. First, higher farm income and adjusted risk attitudes, achieved in both countries through the pathways outlined above, may enhance access to and adoption of resilience-enhancing inputs, such as seeds for flood resistant crop varieties (Nelson et al., 2010). This could also be enhanced by better access to markets to purchase these inputs in the case of Bangladesh. In both countries, as livelihood opportunities increase through the above pathways, vulnerability of livelihoods to climatic stressors can be reduced through income diversification (Ellis, 1999; Lin, 2011; Estruch and Grandelis, 2013). Also, in Bangladesh, the fact that the infrastructure is specifically designed to be climate resilient can help to ensure that access to markets and other services are not disrupted by climatic stressors, thus enhancing the resilience and sustainability of livelihoods and smoothing incomes (Ziervogel and Ericksen, 2010; UN, 2016).

Finally, among beneficiaries of both projects, it is expected that improved rural infrastructure will also contribute to women's empowerment by reducing the economic and social barriers that they face. In both countries, improved agricultural productivity as a result of better infrastructure could reduce the requirements of women to tend the family farm. Also in Bangladesh, the improved roads and markets could improve women's mobility and economic opportunities, and give them more scope to build their social capital. Women's inclusion in the rural transformation process can also be enhanced through the above-mentioned impacts on resilience to climatic shocks. Coping with these shocks can increase women's workloads and force them to forego food for the sake of their family, hardships which may be reduced by increased climate resilience (MacMahon, 2017).

As well as aiming to enhance the size and sustainability of their impacts, the case study projects also target the inclusion of women by providing capacity building support to local institutions. The projects in Bangladesh and the Philippines respectively work through Market Management Committees (MMCs) and Irrigators' Associations (IAs), aiming to increase women's involvement in these groups, and thus improve their standing and voice in their households and communities. However, in the case of IAs, such groups have sometimes been found to exclude women and other vulnerable groups (Meinzen-Dick & Zwarteveen, 1998; Hussain, 2007b; Sargeson & Jacka, 2017).

Figure 1.1 collates the expected impact pathways of the two case study projects outlined above into an overarching Theory of Change around which this thesis is structured.

Figure 1.1. Theory of Change of improved rural infrastructure on inclusive rural transformation



1.5 Research problem

Our objective is to build the evidence base and to inform the design of future projects aiming to stimulate inclusive rural transformation using rural infrastructure. Drawing from the theory of change above, the overarching research problem of this thesis is:

How can improved rural infrastructure impact inclusive rural transformation?

And how may contextual factors help or hinder these impacts?

As outlined in the previous section, there are several theoretical channels through which improved rural infrastructure can (positively or negatively) impact each component of inclusive rural transformation. There are also possible ways that these components can complement each other, with an improvement in one component potentially catalysing a snowballing of the transformation process. To contribute new insights to the overarching research problem, we focus on two types of infrastructure investments: improved irrigation (Chapters 2 and 3) and climate resilient roads and markets (Chapters 4 and 5).

While covering each of the components of inclusive rural transformation, our analysis focuses particularly on the most complex element of the rural transformation process—productivity—for which we conduct analyses on how improving these types of rural infrastructure changes the Frontier Output and Technical Efficiency (TE) of beneficiary farmers (Chapters 3 and 5). Improved agricultural productivity has been the main historic driver of rural transformation, and is central to the theory of change above. Acknowledging its complexity, we analyse two different aspects of productivity—output and efficiency—which allows us to draw richer insights into how farm activities and behaviours have been influenced by the case study projects.

We also particularly consider the cross-cutting effect of increased resilience to climatic shocks—given the growing threat that these shocks pose to the transformation process in developing countries. As mentioned above, the effect of climate change and climate shocks have the potential to derail inclusive rural transformation pathways, and hinder the impact of development projects, meaning they are a key consideration within our overarching research question.

In order to fully address our overarching research question, we collate our findings about how each component of the transformation process is impacted to ask what these imply for the inclusive rural transformation process as a whole. As discussed, it is not necessarily the case that an improvement in one area is beneficial for the speed, balance, sustainability or inclusivity of the overall rural transformation process as a whole. If, for instance, improved infrastructure causes a small positive increase in farm output, but limited progress in off-farm activities or in production efficiency, this could mean that farmers are being encouraged to remain in traditional agriculture, doing slightly better than before, but without the modernisation or diversification that is required for significant long-term change. Such an effect is a particular concern for irrigation, as evidenced by past studies in India and the Philippines (World Bank, 2008b; JICA, 2012). Similarly if incomes increase but assets and social capital, for instance, do not, this implies that incomes are not being invested in improving production capacity and building resilience to shocks, which raises questions about the economic pathways of beneficiaries and the sustainability of these livelihood improvements (Ellis, 1999; Winters et al., 2009).

In terms of the influence of contextual factors, the role of existing market opportunities is of prime importance, as this plays a key role in whether the projects can spur advancement into more lucrative on- and off-farm activities, in terms of demand for their outputs and access to the required inputs (IFAD, 2016). We also focus on the role played by rural institutions, given their widely acknowledged importance to the effectiveness and inclusivity of the impact of rural development projects (Agrawal et al., 2008; FAO, 2012b). Finally, based on findings of past studies, including a recent evaluation of a nutrition project in Bangladesh by Nisbett et al. (2016), we consider the role of social norms for women, (especially in the Bangladesh case study), given the barrier that these can pose to women's inclusion in such contexts.

1.6 Key knowledge gaps

Answering this research problem will help to contribute new insights on the potential links between improved rural infrastructure and the components of rural transformation, as well as on the interactions between the components themselves. As discussed in more detail in the chapters of this thesis, the evidence that has been generated in both cases is patchy, despite rural infrastructure being one of the most costly forms of development spending (Jouanjean, 2013; Knox et al., 2013). Our focus on infrastructure that is designed to be climate resilient, in particular, offers insights on a heavily under-studied area of rural development investment (Douven et al., 2012).

In terms of the links between improved rural infrastructure and inclusive rural transformation, there is some evidence of the positive impacts of better rural roads and irrigation systems on agricultural production, and to a lesser extent on income. However, the potential links between improved rural infrastructure of any kind and other rural transformation indicators remain largely theoretical in nature with limited empirical validation. This includes impacts on asset ownership, livelihood composition, nutrition and social capital. The latter for instance has been cited as the "*forgotten dimension of the SDG indicators*" due to limited recognition of its importance to sustainable development (Verbeek and Dill, 2017). The same applies to climate resilient infrastructure, which apart from all-weather roads has received limited focus in any area. As discussed in further detail in the chapters of this thesis, existing studies also rarely consider details of the impact pathways of improved rural infrastructure, including changes in risk attitudes or climate resilience, or the role played by mitigating factors such as market access, resource endowments of beneficiaries, local institutions, and the type of infrastructure that is being implemented (Hine et al., 2019). Finally, effects on the inclusivity of the transformation of the process is largely absent from the evidence base, an oversight that is a particular concern in the case of women's inclusion, given that projects could potentially entrench or worsen the position of women in their communities.

Apart from the links between agricultural production and income, the potential interactions between the components of inclusive rural transformation are also largely theoretical. As income is rarely disaggregated by source, little is known on the potential links between agricultural production and off-farm activities, for instance, while there has been limited focus on the links between social capital or nutrition with the other components of rural transformation (Cameron et al., 2016). In this thesis, for instance, we particularly consider how improvements in livestock production can influence nutrition. Empirical studies of the links between gender equality and components such as agricultural production and livelihood composition are also limited.

1.7 Contributions

1.7.1. Insights to inform development practice

The two projects provide useful case studies for drawing rich and widely applicable insights for development practice for a number of reasons. First, both projects are located in South Asia, a region that is in the middle of an economic growth boom, but still suffers from considerable economic and social inequality and high poverty rates (Nabi et al., 2010; World Bank, 2019). As the majority of the countries in the region share similar economic and structural challenges—including widespread inequality, unbalanced growth, poor connectivity, and increasing frequent and severe climatic shocks—insights from the two case study projects can be applied to inform a more inclusive growth agenda across the region (Nabi et al., 2010; Goretti et al., 2019). In addition, the two projects: (i) cover three of the main types of rural infrastructure investment (roads, markets and irrigation); (ii) allow us to test the efficacy of a complementary support such as institution building and FFS; and (iii) are implemented across a range of beneficiaries to allow for insightful sub-group analyses.

In terms of contributions to development practice, first, the robust quantitative measurement of the impacts of the two projects, across a much wider range of outcomes compared to most impact studies, can help to ensure that similar future investments are made based on a clearer picture of the expected benefits. As willingness is wavering amongst some donors to meet the estimated $2.5-$3 trillion in additional funds required each year to meet the SDGs, the need for better-informed, more cost-effective development spending is becoming increasingly acute (UNCTAD, 2014; Kharas and Rogerson, 2017).

Similarly, the insights from the thesis can help to inform the design of future rural infrastructure projects in terms of how activities are packaged and the way that they are targeted—helping them to be tailored to a given context to achieve higher impacts. Rural development policy often targets the poorest households with support focused on subsistence production and meeting basic needs, while less poor rural households who have the required resources are targeted with more market- and value chain-oriented support (Deshpande et al., 2018; Devereux et al., 2019). As it is inherently difficult to provide such tailored support through rural infrastructure projects, as the infrastructure usually serves the same function for all users, there is consensus that complementary support is required in order to achieve the desired development outcomes for each strata of rural households (World Bank, 1994; Ali and Yao, 2004; OECD, 2007), and that such targeting should be based on robust evidence (Kharas and McArthur, 2017).

Through the rich sub-group analyses based on both quantitative and qualitative data, the four chapters provide in-depth insights to inform the tailoring of rural infrastructure projects. In analysing the relative impacts on the poorest beneficiaries—focusing on downstream households in Chapters 2 and 3 and landless households in Chapters 4 and 5—we determine the extent to which the packages of support provided by IRPEP and CCRIP were able to reach these households, identify factors that mitigated impacts, and propose additional support required through future projects to overcome them. Moreover, for CCRIP in Chapter 4 we test whether impacts on the poorest and less poor households differs based on the package of infrastructure support that they receive. We also take advantage of differences in exposure to climatic shocks in Chapters 2 and 5, and in market access in Chapters 2 and 3, to investigate the efficacy of the packages of support under these different circumstances, and to identify ways that these challenges could be better addressed in future projects. Across the chapters, we provide particularly in-depth insights into the extent to which building the capacity of local institutions—specifically IAs in Chapters 2 and 3 and MMCs in Chapters 4 and 5—serve to complement the impacts of improved rural infrastructure. Finally, in applying the multi-faceted transformation framework in Chapters 2 and 4, we are able to identify the linkages between the different components of the transformation process that can then be leveraged in future projects.

1.7.2. Contributions to the literature

In addition to the contributions to development practice, the thesis aims to advance impact evaluations conducted on rural development projects by introducing a tailored framework of indicators designed to comprehensively assess impacts on inclusive rural transformation. Applying this new framework allows us to capture how the project has influenced the dynamic rural transformation process, which has important implications for the medium- and longer-term impacts of the project. Impact evaluations of rural development projects commonly focus on a limited set of direct agriculture-related indicators such as yields and income from crop sales, however as stated by Dercon (2013: 184) "*looking at agriculture in isolation is a recipe for misunderstanding the economic transformation in growing economies and the role of agriculture therein*". Highlighting the importance of this, a review of the longer-term impacts of rural development interventions in Bangladesh by Quisumbing et al. (2011) finds that impacts on indicators such as consumption expenditure and asset accumulation often diminished over time, and the authors advocate that considering a wide range of impact indicators at the point of project completion can help to predict whether impacts will be sustained. Doing so can provide indications of how future projects can be improved to achieve sustainable impacts without having to wait several years after the project has finished to conduct a follow-up analysis.

Chapters 3 and 5 add to a limited but growing body of literature that is advancing the rural impact evaluation field by combining Stochastic Production Frontier (SPF) and causal inference techniques to robustly measure impacts on agricultural productivity (Bravo-Ureta, 2014). Further, Chapter 5 provides the first known application of this combined approach to analysing the impact of climate resilient markets and roads. This approach is a valuable addition to the toolkit of impact evaluation methods as it builds upon the relative strengths of the SPF and impact evaluation literature while addressing their shortcomings. In terms of SPF studies that compare different groups of rural producers, these rarely address possible selection bias associated with entry into a given comparison group, whereas, as mentioned, impact evaluation studies of rural development projects rarely go further than using output per hectare to measure impacts on agricultural productivity.

1.8 Materials and methods

The data on the two projects used for this thesis was collected by the author while working as an analyst in IFAD’s Research and Impact Assessment Division. This division is tasked with analysing the impact of 15 per cent of the projects in IFAD’s project portfolio during each financing window, the findings from which are then extrapolated to the rest of the portfolio in order to estimate IFAD’s overall impact to be reported to the Fund’s Executive Board (IFAD, 2019a). The two projects used for this thesis were included as part of the impact measurement exercise for the 2014-2016 financing window (see Garbero, 2016). For each project, the data was collected for the purpose of an official impact report (see Arslan et al., 2018; Arslan et al., 2019), after which the author conducted additional analyses for the chapters included in this thesis.

For each project, the data consists of a large quantitative household level dataset covering treatment and control households, and qualitative data collected through Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs) with beneficiaries, local leaders and key project staff. The household datasets contain agricultural production information by season and parcel, as well as information on all other income generating activities, asset ownership, access to credit, food security and nutrition, education, social capital, exposure to shocks, and women's empowerment. The data for the Philippines also includes a quantitative survey of IAs. The quantitative datasets are cross sectional, and were collected shortly after the projects were completed, meaning that robust statistical techniques are required to produce accurate measurements of impact.

Accurate causal inference of the impact of a development project requires comparing a set of treated households with a set of control households who accurately represent how treated households would have fared in the absence of the project (Winters et al., 2010). Ideally, this type of analysis would involve randomly assigning the project within a pool of eligible households at the baseline stage, thus ensuring that the treatment and control groups compared for the analysis are free from selection bias (Khandker et al., 2010). Selection bias in impact evaluation refers to the presence of unbalanced characteristics between the treatment and control group due to a lack of random selection, and is problematic when the characteristics that are unbalanced have the potential to distort impact measurements (Heckman et al., 1996). As is the case for the majority of development projects, project selection was not random for the IRPEP and CCRIP datasets, meaning that efforts must be taken when designing the sample and analysing the data to mitigate possible selection bias ex-post.

Regarding the design of the quantitative household questionnaire sample, we aimed to reduce potential selection bias by carefully selecting treatment and control households who would have stood a similar chance of being selected for inclusion in the project at the baseline stage. For the IRPEP household dataset, as the project selected beneficiaries by first identifying areas where irrigation systems required improvement and where its users were poor, we applied Propensity Score Matching (PSM) to first identify treated and control irrigation systems that were well-matched according to the selection criteria used by the project, based on data from the year that the project began. For the systems selected through this process, we then randomly selected households from among their registered users. Similarly for the CCRIP household dataset, as the project first identified markets that were remote, climate-vulnerable, and used by poor households, we conducted a similar matching exercise, using project data from the year the project began combined with GIS information to identify treated and control markets that were similar according to the project's selection criteria. As with the IRPEP sample, we then randomly selected households for interviews from within the catchment area of the selected markets.

Using these datasets, the analyses detailed in the chapters of this thesis then apply different analytical methods to further reduce the risk of selection bias and to thus produce robust impact estimates. In Chapters 2 and 4, we analyse the impacts of IRPEP and CCRIP, respectively, on a framework of impact indicators designed to assess the multi-faceted impacts of the projects on inclusive rural transformation. In Chapter 2, we estimate impacts using an Inverse Probability Weighted Regression Adjustment (IPWRA) model. This model reduces selection bias between the treatment and control groups by combining a parametric regression approach that controls for potential biasing covariates, with a Propensity Score-based weighting approach whereby control units are assigned higher weights if they better represent a treatment household. In Chapter 4, we use a method that matches similar treatment and control pairs using a matrix-based distance matching, using which we estimate impacts by taking the average distance in the outcome variable across all of the matched pairs.

In Chapters 3 and 5, we narrow our focus onto the respective impacts of IRPEP and CCRIP on agricultural productivity using a combination of causal inference and SPF techniques. In each case, this involves first applying a PSM technique to the household level dataset to trim the sample of treatment and control households without a sufficiently close match in the opposing group. We then compare the TE and Frontier Output of the trimmed treatment and control households using an enveloping Stochastic Meta-Frontier (SMF). This approach thus allows for robust productivity measurement whilst also controlling for potential selection bias.

In each case these analytical methods produce estimates of the magnitude of the impact of the projects on a range of indicators, both for the full sample as well as relevant sub-groups. In order to uncover the story behind the numbers, we then draw from the qualitative data to identify potential causal mechanisms and contextual factors that may have mitigated impacts.

The main methodological challenge of this thesis is that its analyses are based on ex-post cross-sectional datasets, which could potentially threaten the validity of our impact estimates. Especially in the absence of random allocation to the treatment or control group ex-ante, baseline data can help to considerably reduce selection bias in an impact analysis (Winters et al., 2010). Without random allocation, statistical matching is the most common method for reducing selection bias, and the aim of this matching is to pair treatment and control households who were similar at the baseline stage. Without baseline data, we must try to reconstruct the baseline characteristics of the sample households without real-time data, instead using variables that are fixed over time or variables based on recall by the respondent, which can be prone to error. This risks the validity of the results as treatment and control households may not be paired with a household with whom they were truly similar at the baseline stage, and who therefore do not provide a valid counterfactual.

We take three main measures to mitigate this risk. First, as explained above, we employ carefully-designed samples, informed by administrative data from the baseline stage and input from local project staff, to ensure that treatment and control households are already similar before we come to the data analysis stage. Second, we conduct balance testing to validate our results and use secondary analytical models to cross-reference the results to confirm that they are consistent across specifications. Finally, across the analysis, we draw upon rich qualitative datasets to validate our findings and to look for inconsistencies, based on which we are able to better-interpret and potentially temper the messages we draw from the quantitative results.

1.9 Overview of chapters

In the proceeding chapter of this thesis (Chapter 2), we assess how IRPEP in the Philippines impacted the various elements of inclusive rural transformation amongst the smallholder beneficiaries of the project. To identify factors that may have mitigated the project’s impacts, we take advantage of the heterogeneity of two of the project regions to assess how and why impacts differed in each case. We also analyse whether impacts differ for producers located downstream on the irrigation canals, who are often poorer and suffer from overuse of water by the wealthier upstream producers.

In recognition of agricultural production as the main historic driver of the rural transformation process, in Chapter 3 we narrow our focus onto IRPEP's impacts on the efficiency of agricultural production. Again, we draw upon sub-group analyses using both the quantitative and qualitative data to determine the factors that shaped the project's impacts, separating the sample in several ways, including by the gender and education of the household head, location on the irrigation canal, region, and land ownership.

In Chapter 4, in a similar vein to Chapter 2, we analyse the impacts of CCRIP in Bangladesh on a framework of inclusive rural transformation indicators. To understand the specific causal mechanisms and the circumstances under which the impact pathways are valid, we analyse whether improving both the local market and the market-connecting road has a larger impact compared to solely improving the market, and test the influence of initial resource endowments by analysing if impacts differed according to land ownership.

In Chapter 5, in a similar vein to Chapter 3, we delve deeper into the impacts of CCRIP on the efficiency of agricultural production. Given that this project was specifically designed to increase the resilience of beneficiaries to climatic shocks, the sub-group analysis for this chapter focuses on how impacts differed according to exposure to extreme flooding, both in terms of a one-off event and in terms of cumulative exposure over a prolonged period.

In the concluding chapter we synthesise the quantitative and qualitative insights from the two case studies across the four chapters, discuss their implications for the overarching research questions of this thesis, their contributions to the literature, and their implications for project design and policymaking going forward.

Chapter 2

What role can small-scale irrigation play in promoting inclusive rural transformation?

Evidence from smallholder rice farmers in the Philippines

Abstract: Cultivating inclusive rural transformation is key to sustainable growth and poverty reduction in developing countries, but existing research rarely analyses the impacts of rural development projects on this process. We use a combination of quantitative and qualitative data to rigorously measure impacts and uncover the causal pathways of a canal irrigation project for rice farmers in the Philippines, finding that positive impacts were heavily determined by market access and the strength of the local economy. We also find limited impacts for poorer farmers located further downstream on the irrigation canals. Based on these findings, we draw several lessons about the complementary conditions and support that are required in order for irrigation to be an effective tool in promoting inclusive rural transformation in developing countries.

This chapter is based on:

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2.1 Introduction

It is well-documented that improved irrigation increases agricultural productivity, but higher crop yields alone are not enough to drive transformational change for rural households (Lipton et al., 2003; Pinstrup-Andersen and Shimokawa, 2006). While rising crop productivity is important, sustainable and inclusive rural transformation also involves changes in the composition of livelihood activities and continuous improvements in incomes, assets, off-farm productivity, social capital, nutrition, education and gender equality (IFAD, 2016; FAO, 2017). By increasing and stabilising yields, along with other mechanisms, better irrigation has the potential to contribute to each of these aspects of inclusive rural transformation, but empirical evidence on its wider impacts is scarce.

This chapter addresses this research gap with an in-depth impact evaluation of a small-scale irrigation project for smallholder rice farmers in the Philippines, in a bid to inform ongoing efforts to shape and accelerate the most desirable forms of rural transformation in developing countries. We focus on small-scale irrigation in particular because the low cost of its construction and maintenance means it is well suited to supporting smallholder farmers, who make up the majority of the producers in the country (Xie et al., 2014). Focusing on irrigation systems that are user-managed also helps to fill a significant knowledge gap on the benefits of this type of local governance structure, about which there remains some doubts (Senanayake et al., 2015).

We use a combination of quantitative and qualitative data from treatment and control households to analyse the project's impacts on a set of indicators within a novel inclusive rural transformation framework. As part of the investigation, we take advantage of the differences between the project regions to identify important contextual factors that shaped impacts. To our knowledge, this is the first impact evaluation study to apply an inclusive rural transformation framework in this manner.

The remainder of the paper first outlines the potential linkages between small-scale irrigation and inclusive rural transformation around which the framework of impact indicators is based. This is followed by an overview of the case study project; details of the data and methodology; a profile of the sample; a presentation and discussion of the results; and the conclusions and policy implications.

2.2 Potential links between small-scale irrigation and inclusive rural transformation

There is a large body of evidence showing that well-managed irrigation systems help farmers to increase their cropping intensity and cultivate year-round, leading to higher and more stable crop yields (Lipton et al., 2003; Hussain and Hanjra, 2004; Pinstrup-Andersen and Shimokawa, 2006). This effect on agricultural production can contribute in-turn to the rural transformation processes in several ways. As evidenced during the Green Revolution, for instance, more reliable production can promote agricultural modernisation by increasing farmers' incentives to adopt new technologies (Evenson and Gollin, 2003; Estudillo and Otsuka, 2006; Hazell, 2009). Improved irrigation could also promote higher-value, market-oriented agricultural production by increasing farmers' production capacity and marketable surplus, and potentially by allowing farmers to grow cash crops that are hard to grow with rain-fed irrigation (Namara et al., 2010; Burney and Naylor, 2012). In Bangladesh, for instance, Mottaleb et al. (2015) find that better irrigation infrastructure increased rice farmers' market integration thanks to their increased marketable surplus, while Mishra et al. (2018) find a positive link between irrigation and contract farming among smallholders in India.

In addition, more reliable and efficient crop production could also change risk attitudes and reduce labour requirements, both of which may encourage farmers to advance into the type of productive off-farm activities characteristic of a transforming economy (Freguin-Gresh et al., 2012). As irrigation water can also be used to improve grazing lands and for other livestock needs, better irrigation can especially encourage more livestock production, a link supported by evidence from Mali and Nepal (Dillon, 2011; ADB, 2012).

Although largely untested, better irrigation could also theoretically contribute to improved nutrition, education and social capital, all key components of a sustainable rural transformation process. Better nutrition and food security may be achieved as households consume more fruits, vegetables, staples and livestock products thanks to their higher crop yields, enhanced livestock production and greater market integration. Higher labour productivity and income as a result of better irrigation could also reduce the need for children to work on family farms, leading to higher school enrolment and attendance (FAO, 2012a). An irrigation project in Madagascar, for instance, was found to have increased incomes, and as a result, increased the amount that farmers spent on their children's education (Ring et al., 2018). Higher education also has the potential to in-turn complement the impact of irrigation on productivity as part of a virtuous cycle (Hanjra et al., 2009). Social capital could be improved through user-led irrigation schemes, a common aspect of small-scale irrigation which can increase social cohesion and mutual support (Kähkönen, 1999). An irrigation project in Mali, for instance, found evidence of increased meal sharing as a form of risk protection (Dillon, 2011). As with education, higher social capital can also feed back into the performance of the irrigation system by increasing collective action within user-led management systems, as has been found among water user associations in Japan (Takayama et al., 2018).

The capacity of better irrigation to promote a more inclusive form of transformation lies in its potential benefits for smallholder farmers as well as women, two of the groups most at risk of exclusion (FAO, 2017). Regarding smallholders, small-scale irrigation systems are cheaper to implement and maintain, making them an accessible and sustainable option for these farmers. Among smallholders, those located downstream—who are usually the poorest and often suffer from overuse of water by those located upstream—stand to benefit the most from more efficient and better-managed canal systems (Namara et al., 2010; Darko et al., 2016). Moreover, research shows that where there are low transmission losses and other supporting factors, equitable irrigations systems are also the most productive for all users (Steiner and Walter, 1992).

Women could benefit through new economic opportunities as livelihoods are enhanced through the mechanisms discussed above. However, there is also potential for women to be left to tend the family farm while men pursue other high-value activities (Smith 2004; Slavchevska et al., 2016). When they engage in democratically managed user-led water management groups, women could also improve their representation and responsibilities within their communities (Sargeson and Jacka, 2017). In practice, however, these groups tend to suffer from high levels of exclusion, especially of women (Meinzen-Dick and Zwarteveen, 1998; Hussain, 2007).

Of the few existing studies that analyse the impact of irrigation on outcomes other than yields, the findings are not all positive, and some even demonstrate how irrigation can hinder the rural transformation process by making livelihoods more static. Studies of small-scale irrigation projects for rice farmers in the Philippines and India that compared treatment and control groups to measure impacts both found that improved irrigation led beneficiaries to consolidate their livelihoods around rice production, while control households diversified and were able to keep pace with the income improvements of beneficiaries (World Bank, 2008b; JICA, 2012). Without sufficient gains from specialisation, such an effect can hinder income growth and increase vulnerability to crop-specific shocks, thus reducing resilience and potentially hindering livelihood choices and technology adoption (Feder et al., 1985; Lin, 2011; Makate et al., 2016). There is also evidence that a lack of crop diversity can have a negative effect on dietary diversity and nutrition (Sekabira and Nalunga, 2020).

For the same projects, and another in Madagascar, impacts on inclusivity were also doubtful (World Bank, 2008b; JICA, 2012; Ring et al., 2018). In each case, a failure of collective action and instances of elite capture within the user groups led to inequitable water distribution and hence increased inequality between up and downstream households. This confirms a common concern about small-scale canal irrigation that, without effective institutions managing the systems, the benefits of irrigation are likely to be unequal and captured by wealthier farmers located upstream (Magistro et al., 2007; Meinzen-Dick, 2007; World Bank, 2008b; Burney and Naylor, 2012). Irrigation governance is a contested issue, and despite knowledge gaps and doubts over their effectiveness that are fuelled by findings such as those above, there are growing calls for an increase Irrigation Management Transfer, particularly in Africa, and for user-led water management institutions to be provided with more support, responsibility and involvement in policy formation (Senanayake et al., 2015; Mutambara et al., 2016; IFAD, 2018a).

Findings from the studies mentioned above indicate that contextual factors such as the strength of local institutions will be important in determining which of the potential positive and negative links between irrigation and rural transformation are realised. The quality of local markets for inputs, outputs and credit are also likely to play an important role. Shifts in livelihood activities and benefits from specialisation, for instance, cannot be supported through irrigation without market and value chain connectivity (Namara et al., 2010; Freguin-Gresh et al., 2012; FAO, 2017).

2.3 Details of the case study project

IRPEP was implemented in Region VI (Western Visayas), Region VIII (Eastern Visayas) and Region X (Northern Mindanao) of the Philippines between 2010-2015, with a budget of $25 million. By the time of its completion, the project had provided support to 109 Communal Irrigation Systems (CIS) and the Irrigators' Associations (IAs) that manage them, covering 9,347 hectares of land. CIS are small-scale canal diversion irrigation systems that cover areas no larger than 1,000 hectares and account for around 35 per cent of the total irrigated land in the country (NIA, 2017). The project targeted smallholders because they represent one of the country's poorest groups, due mainly to their low productivity and frequent exposure to climatic shocks, issues exacerbated by the low irrigation coverage in the country (Bordey et al., 2016).

IRPEP targeted CIS that had inadequate or inefficient water supply but high potential for improvement, and whose users had low income and crop productivity. For each of these CIS, IRPEP extended the canals of the CIS to cover more land, repaired canals damaged by climatic shocks, and lined canals with concrete to prevent water seepage. In addition, IRPEP provided training to IA officers to manage the system sustainably and equitably, encouraged women's participation in IAs, and offered marketing facilitation services. By lining the canals to reduce transmission losses, and improving system management, a key aim of the project was to improve water supply to households located downstream on the canals.

The project is likely to have impacted the three regions differently. For instance, Region VI and VIII are more at risk of climatic shocks compared to Region X. In fact, Region VIII was very severely affected by Super Typhoon Haiyan during the project's implementation, which caused serious damage to infrastructure and strained local institutions to cope with the implications—ultimately leading to them being excluded from this study so as not to distort the findings. Region X is much wealthier and its economy is mainly focused on cash crop production compared to Region VI, which is more focused on rice and livestock production and has a services sector (PSA, 2016). Despite being poorer, Region VI has experienced much larger poverty reduction in recent years, while growth in Region X has been less pro-poor, an issue attributed partly to the poor connectivity of households in rural areas (NEDA, 2017b; NEDA, 2017c; de la Rosa, 2018).

2.4 Data and methodology

2.4.1 Data and indicators

The quantitative data comes from a household questionnaire administered 18 months after IRPEP's completion. We use data from 580 households in Region VI from 20 treatment and 20 control CIS, and 566 households in Region X from 16 treatment and 17 control CIS, equally split between beneficiary and control households.[1]

Several measures were taken during both the sampling and data analysis stages to obtain comparable treatment and control groups to measure IRPEP's impact. In the sampling stage, we first used PSM to identify similar treatment and control CIS from a longlist of all the CIS in the two regions, with the scores calculated to represent the likelihood of a CIS being selected for IRPEP (Khandker et al., 2010). These scores were created using pre-project data linked to the project's selection criteria, including the average yields of users, distance to the regional capital, and the percentage of the system that is operational. By removing CIS without at least one match in the opposite group, we used the scores to create a shortlist of potential treatment and control CIS, from which we selected the final set for the sample with expert input from project staff. From these CIS, we randomly selected households from amongst the CIS users for the household survey. After the data was collected, we verified the sample and removed 29 treatment households who still did not have access to rehabilitated irrigation, and 195 control households who had already received similar irrigation support from the Philippines government.

Complementary qualitative data were collected through KIIs and FGDs. This included a KII with the National Project Coordinator and one FGD with other project staff at the national level, along with a KII and three FGDs with regional staff in each of the three project regions. In addition, 12 FGDs were held with officers from 6 treatment and 6 control IAs of the selected CIS, and 12 KIIs were also held with the Presidents of the same 12 IAs.

[1] The sample size was determined based on obtaining a Minimum Detectable Effect Size of 10%, using the formula outlined in World Bank (2007).

In order to test the potential linkages between irrigation and inclusive rural transformation outlined above, we use the household dataset to create indicators relating to agricultural production, income, livelihood composition, asset ownership, nutrition, social capital, education, and women's inclusion. Regarding agricultural productivity, we focus on rice production given its importance for smallholder livelihoods and because too few households grew other crops to facilitate a meaningful analysis. To represent asset ownership, we create an index that incorporates ownership of a range of productive assets, calculated using principle component analysis (Filmer & Pritchett, 2001). We also create an index for livestock ownership based on Tropical Livestock Units (Jahnke, 1982). Household Dietary Diversity Scores are used to assess impact on nutrition, whereby a score is assigned based on the consumption of different food groups in the past 24 hours (FAO, 2010).

To assess impacts by parcel location, we compare key indicators from each impact domain for households who used only downstream parcels during the study period against households who used at least one up or midstream parcel. This classification was chosen so as to focus on those households likely to be the poorest (as all of their parcels are downstream)—although only a small percentage of households had a mix of up, mid and downstream parcels.

2.4.2 Impact estimation methodology

We estimate the average treatment effect on the treated (ATET) for IRPEP using an IPWRA approach, an impact estimation method that improves the comparability of the treatment and control samples using both weighting and regression adjustment (see Wooldridge, 2010; Austin and Stuart, 2015).

In this model, all treatment households are assigned a weight of one, and control households are assigned a weight that represents the inverse of the probability of their being a control household. These probability weights are calculated in a similar way to the Propensity Scores created for the sample design, whereby the likelihood of being in the treatment or control group is modelled based on pre-project livelihood capacities and other factors likely to influence their participation.[2] Using the inverse of the probability means that we assign greater weight to control households who better represent a common treatment household, rather than a common control household. We employ the IPWRA model as it allows for the use of additional control variables within a regression framework which are important to incorporate in the case of detailed agricultural data, and does not require the dropping of a large number of households as with some PSM algorithms.

Formally, these weights are calculated as follows:

$$IPW_{ATET} = \mathrm{T} + \frac{P(1-\mathrm{T})}{1-P} \qquad (2.1)$$

where T = the treatment status (1 = treated, 0 = control), and P = the probability of receiving the treatment they received given the set of weighting variables.

The next step is to run a regression adjustment model with the weights applied to each household. Separate models are run for the treatment and control groups, and in each case an expected value for the impact indicator is estimated. The formal specification of the regression model is as follows:

[2] The variables used to the create the scores consisted of the age, education and gender of the household head, household size, asset ownership at the start of the project, climatic shocks in the past year, number of IA members in the household, amount of land owned and proportion of land owned up/mid/downstream on the irrigation canal.

$$Y_i = \beta_0 + \beta_1 T_i + \Sigma X_{ij}\beta_{2j} + e_i \qquad (2.2)$$

Where Y is the outcome for household i for the impact indicator, T_i is the treatment status for household i, X_{ij} represents an I x J matrix of control variables used in the model, β_1 is the coefficient of the treatment indicator and β_{2j} is a vector of coefficients to be estimated for each of the control variables, β_o is the constant, and e_i is the error term, which was calculated using a cluster robust estimator at the province level (Cameron and Miller, 2015). Control variables were chosen based on their likelihoods to have influenced the outcome variable, while not having been affected by the project, meaning that different sets of control variables were used depending on the outcome variable being analysed. [3]

The final estimated impact, the ATET, is then calculated as follows:

$$ATET = \hat{Y}_1 - \hat{Y}_o \qquad (2.3)$$

Where $\hat{Y}_1$ is the average expected outcome for the treatment households, and $\hat{Y}_o$ is the average expected outcome for control households obtained from the regression in Equation 2.2 above.

Both the inverse probability weighting and regression adjustment components of the IPWRA model can be used individually for this type of impact analysis, but to produce consistent estimates, the former is dependent on the weights being correctly specified and the latter is dependent on the correct-specification of the regression model. However, the IPWRA model

[3] Control variables for each impact indicator were selected from the following list: Province; Location on irrigation canal; Distance from local market; Education of household head; Age of household head; Average age in household; Number of adults in household; Household size; Experiences drought/flood/pest outbreak shock in past year; Soil fertility; Hectares of land owned; Received training on rice production/water management/input subsidy; Received loan in past 12 months; Baseline asset index.

only requires one of the two to be correctly specified for the estimates to be consistent, therefore the model is classified as a doubly-robust estimator.

Tests of the effectiveness of the model indicate that we were able to further reduce the minor imbalances between treatment and control the households . For the variables used to weight the sample, the Standardised Mean Difference (SMD) was reduced from 0.09 to 0.07, and the Variance Ratio (VR) was reduced from 1.11 to 1.09.[4] To test the sensitivity of the results to model specification, the results were also verified using a secondary model based on a nearest neighbour PSM algorithm (Austin, 2011), which produced qualitatively similar results, suggesting that our findings are consistent across model specifications.[5]

2.5 Profile of the sample

Table 2.1 presents descriptive statistics on livelihood characteristics for the household samples from Regions VI and X. For both regions, average incomes are both well below the national average of PHP140,259, as well as the regional averages of PHP76,459 for Region VI and PHP120,799 for Region X (PSA, 2016). Although income and land use in Region VI are considerably lower than in Region X. Rice production is widespread amongst the sample but average harvests are larger in Region X and a much larger proportion of harvests are sold rather than consumed in this region.

Although poorer, the livelihoods of households in Region VI are more diversified compared to households in Region X, with the latter more dependent on rice sales. This diversity in Region

[4] An SMD of below 0.1 is recommended for a well-balanced sample (Austin, 2009).
[5] Results from this secondary model are available upon request from the corresponding author.

VI may be survival (rather than opportunity) based, given their lower incomes, lower land access, and higher risk of climatic shocks (Ellis, 2000; Svodziwa, 2018). Conversely, households in Region X may show signs of transformation in terms of the benefits they are gaining from specialising in rice farming, but they do not show signs of shifting into more lucrative on- and off-farm activities. They also seem to face barriers to their rice marketing, with further investigation finding that the majority of the rice sold by these farmers was unprocessed. Qualitative data from the region also highlights that CIS in the region are located far from local government offices and trading centers, a disconnection which may explain why their profile differs from their wealthier, cash-crop producing rural neighbours in the rest of the region.

Table 2.1. Livelihood characteristics of the household sample

	Region VI	**Region X**
Land cultivated (ha.)	1.7	2.3
Crops grown (% of sample):		
- Rice	99.8	100.0
- Other	4.3	5.6
Rice harvest (t/ha)	3.3	3.7
Proportion of rice harvest sold (%)	16.9	42.6

	Region VI	**Region X**
Income ($/cap.)	932	1,348
Income sources (% of total):		
- Rice sale	14.1	46.0
- Other crop sale	0.4	0.7
- Waged labour	25.0	22.5
- H'hold enterprise	19.2	10.4
- Livestock	7.9	4.0
- Other (remittances, inheritance, etc.)	33.4	16.5

2.6 Results and discussion

2.6.1 Agricultural production and income

Table 2.2 presents the results for IRPEP's impact on rice production per hectare, cropping intensity, production efficiency and rice sales in Region VI and X (the mean values for each of the impact indicators can be found in Appendix 2.A). We find that rice yields were significantly increased in both regions, but more so in Region VI (13 per cent compared to 8 per cent). However cropping intensity—measured by the proportion of operable land that was cultivated—was only increased in Region X and was significantly reduced in Region VI. The efficiency of production—measured by the value of inputs (not including land) used to produce one tonne of rice—was only improved in Region X. Apart from land use, insights from the qualitative data suggest that efficiency of production was not impacted in Region VI due to farmers being unable to afford or access efficiency-enhancing inputs such as improved seed varieties.

Only in Region X did the project increase the proportion of rice harvest that was sold (by nine percentage points) and income from rice sales (by 128 per cent). In Region VI, further analysis finds that there was instead a significant increase in the proportion of harvest used to pay back costs incurred during production. Insights from the qualitative data suggest that this outcome was partially caused by farmers taking loans from local traders to fund their production, which then had to be repaid with their harvest.

The large impact on income from rice sales in Region X seems to have been driven by the increase in yields, rather than improvements in marketing. Qualitative data from Region X highlights similar issues of farmers being tied into credit-for-harvest arrangements with local traders, along with high transport costs and limited access to post-harvest processing machinery. IA leaders also reported that they have attempted to establish collective crop selling and value chain access for their members, but have failed due to farmers' persistent sale to local traders based on traders' lower processing requirements and the credit and immediate payment they provide. In a similar vein, it was widely reported that the marketing support provided by IRPEP, which was not provided in Region VI, was largely ineffective for the same reason, and thus is unlikely to be the reason for the different impacts in the two regions.

We were unable to analyse the project's impact on crop diversity as very few households grew crops other than rice in the two regions, which implies that the project's impacts on agricultural productivity were restricted to rice production. For projects like IRPEP that are focused around the production of a single crop, it is expected that the economic benefits from specialisation counteract the potential increase in households' vulnerability to crop-specific shocks, however such benefits are only reflected in farm incomes in Region X.

Table 2.2. IRPEP impact on agricultural production and sales

	Harvest/ha.	Cropping intensity†	Input expt. per tonne of output	Per cent of harvest sold†	Rice sale revenue/ha	Obs
Region VI	13.31%***	-12.48***	1.05%	-0.12	-5.90%	441
Region X	8.08%***	27.79***	-10.10%***	9.27***	127.50%***	480

Note: *,** and *** indicate that the estimated impact is statistically significant at the 10, 5 and 1% levels, respectively.
Households not producing rice are not included in the model (Region VI = 26; Region X = 17).
† Coefficient represents a percentage point change.

2.6.2 Household income and livelihood composition

Despite the lack of impact on rice sales in Region VI and the large impact in Region X, we find a 19 per cent increase in income for households in Region VI, compared to a significant increase of just 0.4 per cent in Region X (see Table 2.3). The livelihood composition results in the table show that there was a shift in both regions. In Region VI, the share of income from crop sales reduced significantly by five percentage points, which reflects the reduction in cropping intensity noted above, while the share from the sale of livestock products and from off-farm waged labour increased by five and three percentage points, respectively. Additional analysis finds that livestock income per capita increased by 193 per cent in this region. In Region X, the share of income from crop sales increased significantly by 11 percentage points, while the share from off-farm waged labour reduced significantly by nine percentage points. We also find reductions in the share of income from livestock production and household enterprises, but these results are not statistically significant.

These results highlight the potential for opposing impacts of small-scale irrigation projects on livelihood composition based on context; impacts which can help or hinder the rural transformation process. Households in Region VI are poorer but with more diversified livelihoods, have restricted access to agricultural inputs, and are more at risk of climatic shocks. Livestock production is also a major part of the rural economy. IRPEP's impacts in this region indicate that the project helped to enhance households' already-diversified portfolio of activities, further reducing concentration on staple crop production and increasing the benefits from existing market linkages in livestock as well as off-farm waged activities—all signs of advancement in rural transformation at the household level.

The results in Region X have less positive implications. Here, although wealthier, households began with a restricted range of livelihood activities which the project seems to have entrenched. Although gaining somewhat from their specialisation in rice production, the marketing barriers they face mean that these gains have been insufficient to justify this concentration in terms of total household income—echoing past studies in the Philippines and India (JICA, 2012; World Bank, 2008b). Livelihood concentration is usually driven by the prospect of significant gains from specialisation or due to a lack of opportunities to diversify (Freguin-Gresh et al., 2012). The relative poverty of the beneficiaries in this region and the constraints to their rice marketing, along with the region's issues with connectivity and inequality, implies that their increased specialisation may be due to a lack of other opportunities.

Table 2.3. IRPEP impact on household income

		Proportion of household income from:†					
	Total income per capita	Crop sale	Livestock	On-farm waged labour	Off-farm waged labour	Household enterprises	Obs
Region VI	18.65%***	-5.12***	5.16***	-0.85***	3.28***	1.18	467
Region X	0.35%***	11.44***	-14.06	-0.43	-9.00***	-1.66	497

Note: *,** and *** indicate that the estimated impact is statistically significant at the 10, 5 and 1% levels, respectively
† Coefficients represent a percentage point change.

2.6.3 Assets, nutrition, social capital and education

Presented in Table 2.4, we find that ownership of livestock and of other productive assets both increased significantly in Region VI. Dietary diversity, an indicator of nutrition, was also significantly increased, as was involvement in community groups, an indicator of social capital. Regarding education, we find a large positive but non-significant impact on enrolment, which may be linked to the low sample size (as the sample is restricted to households with school age children). For Region X, we do not find significant impacts on any of these indicators.

The different impacts on these indicators in the two regions are seemingly linked to the larger impact on income in Region VI. In the qualitative interviews, households in Region VI noted that they used higher incomes from the project to purchase healthier foods and to send their children to school. In addition, the project's support to IAs may have also contributed to the impact on social capital. In the qualitative interviews, it was highlighted that the strengthened IAs in both regions helped to increase community engagement, although the lack of impact in Region X suggests that households may have faced additional barriers to improving social capital in this area.

These results also highlight important links between small-scale irrigation, livestock, and dietary diversity. In Region VI, we find livestock ownership and income to have increased, similar to findings from previous studies in Mali, Nepal and Vietnam (Dillon, 2011; ADB, 2012; Nguyen et al., 2017). Furthermore, enhanced livestock activities may have also contributed to improved dietary diversity in Region VI, as further analysis indicated that the project had a significantly positive impact on the consumption of both meat and eggs in the region.

Table 2.4. IRPEP impact on assets, nutrition, social capital and education

	Productive asset index	Livestock ownership (TLU)	Dietary diversity score	Group meetings	Obs	School enrolment (% enrolled) †	Obs
Region VI	0.07**	1.10***	0.18***	3.95***	467	10.35	233
Region X	0.09	0.30	0.04	0.73	497	-2.74	260

Note: *,** and *** indicate that the estimated impact is statistically significant at the 10, 5 and 1% levels, respectively
† Coefficients represent a percentage point change. Note that the number of observations for school enrolment model is lower as the it only includes households with school aged children.

2.6.4 Women's inclusion

Table 2.5 shows that the favourable impacts in Region VI also apply to women's inclusion in economic activities. In Region VI, we find a significant increase of four percentage points in the share of household income provided by women's income from waged labour and from household enterprises that they own, and a significant increase of six per cent in the likelihood of a female household member owning their own enterprise.

For both regions, analysis of data collected from IAs also suggests that the project increased the number of women serving as IA officers. This impact could potentially have been mutually complementary to the impacts on women's economic inclusion in Region VI. Women's involvement in collective action groups can enhance their income generating capacity by increasing their economic opportunities and credit access, providing protection from risk, transferring knowledge and skills, and providing assistance in long-term asset accumulation (Pandolfelli et al., 2007; Quisumbing and Kumar, 2011; Schroeder et al., 2013). In-turn, the breaking of social norms achieved through autonomous income generation, more knowledge and assets, and increased strength in numbers can lead to increased representation and standing of women in their communities and households (FAO, 2011b).

In Region VI, these results suggest that women were not excluded from the positive contributions of the project to rural transformation. Furthermore, women's increased economic activities may have contributed to the impact on total household income, and their increased income and bargaining power may have also fed into the positive impacts on education and nutrition. Conversely in Region X, women's economic opportunities do not seem to have changed, as part of the project's overall lack of influence on components of rural transformation in the region.

While in Region VI, the expansion into livestock production and non-farm activities likely presented more opportunities for women to increase their income generating capacities, the increased focus on farm production in Region X likely restricted their activities to family farming (Slavchevska et al., 2016).

Table 2.5. IRPEP IA level impact on women's empowerment

	Women's wage and enterprise income (% of total) †	Likelihood of owning enterprise (%)†	Obs
Region VI	4.09***	5.54***	437
Region X	-3.67	-2.98	474

Note: *,** and *** indicate that the estimated impact is statistically significant at the 10, 5 and 1% levels, respectively. Households where there are no women were not included in the model (Region VI = 30; Region X = 23).
† Coefficients represent a percentage point change.

2.6.5 Impacts by parcel location

There were significant positive impacts on rice yields and rice sale income for households that cultivated downstream parcels (Table 2.6). Respondents in the qualitative interviews attributed this mainly to better regulation of water use along the canals by IAs. Although the yield impact was very similar, households with up or midstream parcels had a much larger impact on rice sale income. Despite this, we do not find a significant impact on total income for either group. There was also no impact for either group on women's income, but there was a significant positive impact for downstream households on group meeting attendance. Not shown in the table is the impact for these households on income composition, for which the majority of income sources were not significantly impacted, except that the proportion of income from selling rice increased for up and midstream households.

Given their restricted irrigation water supply before the project, downstream households were expected to benefit relatively more from the project if they had the same amount of access to inputs as those further upstream. The similar yield impacts for the two groups thus implies input constraints may have hindered poorer downstream households from fully capitalising on the improved water supply, something that is supported by the qualitative data.

The smaller impact on income from rice sales for downstream households indicates that downstream households may also face greater obstacles to market access. The impact on income for up and midstream households echoes that for the wealthier households in Region X, whereby large rice income gains were counteracted by reduced involvement in other activities. However, the opposite effect was not found for downstream households as was found for the poorer households in Region VI, implying the diversification benefits for poorer households were specific to Region VI. The positive impact on social capital for downstream households without a significant impact on income suggests that this impact was driven by increased involvement of these households in communal activities of the CIS and IA, potentially due to the productivity benefits.

Table 2.6. IRPEP impact on up and downstream households

	Harvest/ha.	Rice sale revenue/ha.	Obs	Total income per capita	Group meetings	Women's wage and enterprise income (% of total) †	Obs
Up/midstream	9.21%**	148.67%***	490	6.17%	-0.21	-3.45 (487)	514
Downstream	9.21%***	30.56%***	431	17.20%	1.67**	0.52 (424)	450

Note: Households not producing rice are not included in the model for the first two columns (Region VI = 26; Region X = 17).
*,** and *** indicate that the estimated impact is statistically significant at the 10, 5 and 1% levels, respectively.
† Coefficient represents a percentage point change.

2.7 Conclusions

In this chapter, we find that user-managed small-scale irrigation can play a useful role in promoting inclusive rural transformation, but its impact is shaped by several contextual factors. In one project region that provided a supportive environment, we find that small-scale irrigation projects have the potential to contribute considerably to inclusive rural transformation. Before the project, households in Region VI were reasonably well-connected (living in a small but densely populated area), and the regional economy was structured to provide opportunities for rewarding livelihood expansion. In addition, due to exposure to frequent climatic shocks, the livelihoods of households in this region were characterised by diversification for survival and risk mitigation. For smallholders within this context, there is evidence that already-diversified livelihood activities can be enhanced and become more characteristic of the lucrative activities typical of a transforming rural economy. This impact on livelihoods comes particularly through fruitful links between irrigation and livestock, and is also reflected in more income generating opportunities for women.

In the other project region, however, less enabling local conditions led to limited impacts on the components of inclusive rural transformation. We find that, where smallholders' livelihoods are more static, and issues of connectivity, market access and unbalanced economic growth hinder livelihood expansion and value chain access, projects such as IRPEP struggle to contribute to inclusive rural transformation by themselves. In the worst cases, broader strategies to modernise the rural economy and to draw labour into more productive rural and urban sectors could even be hindered as smallholders become entrenched in existing livelihood activities and potentially become more vulnerable to shocks.

The finding that improved water supply and regulation can benefit downstream households in terms of yields and on-farm income is promising, and highlights the benefits of supporting IAs to manage systems equitably. Broader livelihood benefits for these households, however, may be hindered by poverty-related obstacles such as limited access to inputs and markets.

Based on these results, if small-scale irrigation is to be used as a tool to promote inclusive rural transformation, it must be combined with strategies to foster complementary market linkages at the household level. These strategies must focus on building strong agricultural input and output markets (including financial markets), and opportunities to expand livelihoods into more lucrative on- and off-farm activities. Particular attention is needed to ensure the inclusion of smallholder farmers, especially those located downstream, and rural women, who often face more obstacles to market access and inclusion (FAO, 2017). The strong link between small-scale irrigation and livestock production is surely an opportunity to capitalise upon in this case, given the rising urban demand for animal protein in developing countries (Henchion et al., 2017).

Regarding the specific components of inclusive rural transformation, we add further evidence supporting the link between irrigation and yields. However, we note that improvements in production efficiency can be hindered by input and credit access constraints, which can subsequently limit benefits from crop sales. In addition, we find that increased income and livestock ownership from improved irrigation can increase dietary diversity, consumption of livestock products, and social capital, with the latter also being improved through strengthened IAs. Finally, on the under-studied link between small-scale irrigation and women's empowerment, we find that improving irrigation infrastructure and encouraging women's involvement in its management can considerably improve women's economic opportunities and their role in the community.

Our results also highlight that the effectiveness of using local institutions to manage small-scale irrigation systems, if these institutions are provided with appropriate support. We find that these institutions can provide effective and efficient system management to the particular benefit of those located downstream and provide an avenue for women to gain greater responsibility and representation in the community. Based on our findings, an avenue for future initiatives could be to equip these institutions to provide further support to the livelihoods of system users in ways that address the input, market and credit access barriers that mitigated the impacts of IRPEP.

Appendix 2.A. Mean values of impact indicators

Agricultural production and sales		
Harvest per ha (tonnes)	3.55	3.44
Cropping intensity (%)		
Total input expt per mt of output (PHP)	145.97	143.11
Per cent of harvest sold (%)	33.23	30.97
Rice sale revenue per ha. (PHP)	438.96	403.42
Household income		
Total income per capita (PHP)	1142.70	1145.23
Proportion of household income from:		
– Crop sale	31.46	30.24
– Livestock	5.98	8.29
– On-farm waged labour	2.18	1.85
– Off-farm waged labour	20.19	23.93
– Household enterprises	15.13	14.14
Assets, nutrition, social capital and education		
Productive asset index	1.14	1.06
Livestock ownership (TLU)	2.38	1.58
Dietary diversity score	7.41	7.07
School enrolment (% of school age children enrolled)	93.41	91.50
Group meetings	6.25	5.50
Women's inclusion		
Women's wage and enterprise income (% of total)	15.95	18.46
Likelihood of owning enterprise (%)	17.93	18.06

Chapter 3

Measuring the impact of improved irrigation on the productivity of smallholder rice farmers in the Philippines

A Stochastic Meta-Frontier analysis

Abstract: Using a Stochastic Meta-Frontier approach, we analyse how improved canal irrigation can affect the Technical Efficiency and Frontier Output of smallholder rice farmers. We find that the project had a positive impact on Frontier Output but not on Technical Efficiency, suggesting that improved irrigation technology increased beneficiaries' production potential, but it did not improve efficiency likely due to insufficient training and input access. Heterogeneity analysis reveals that the main beneficiaries were downstream parcels, smaller parcels, those located in the poorer project district, and farmers with lower education, all implying a more pro-poor impact. Finally, we find that female-headed households benefitted less from the project, suggesting the need for additional support in future interventions.

This chapter is based on:

Bravo-Ureta, B.B., Higgins, D. and Arslan, A. 2020. Measuring the impact of improved irrigation on the productivity of smallholder rice farmers in the Philippines: A Stochastic Meta-Frontier analysis. *World Development*, 135: 105073

3.1 Introduction

Given its historic role in catalyzing rural transformation, better farm productivity is central to any attempts to foster inclusive rural transformation in developing countries. However, productivity gains are becoming increasingly threatened by growing water scarcity. Caused by increasing demand from agriculture, mining, industry, hydroelectricity generation, and a rising population (USGCRP 2017; World Bank 2016; de Fraiture et al. 2010), this scarcity is being exacerbated by the melting of glaciers and changes in precipitation patterns, events that have been connected to climate change and that are altering hydrological systems with negative effects on the quantity and quality of water resources (USGCRP 2017; IFAD 2016; IPCC 2014).

Given the challenges climate change is expected to pose on smallholder agriculture, irrigation has been identified as an important adaptation strategy to increase agricultural productivity, and thus to promote inclusive rural transformation in developing countries (World Bank 2017; IFAD 2016). As the potential for bringing additional land under irrigation is limited (FAO 2012), a key strategy is to focus on improving water management efficiency in agriculture, which is especially important in developing countries where farming can account for over 90 per cent of water use (Doungmanee 2016; FAO 2011).

Our concern in this chapter is rice production, which is a central crop for many of the rural poor in terms of caloric and protein intake, overall food consumption, employment, income, and labor and land use in small-scale farms (Muthayya 2014; GRiSP 2013). Rice is also the crop with the highest water use in the world (approximately 784 billion m^3/year), which is more than double the amount of water used for maize or wheat (Chapagain & Hoekstra, 2010). Coping with this water demand requires sizeable investments in irrigation infrastructure and large operating and maintenance budgets (Bouman 2009; Chapagain and Hoekstra 2010).

Despite the importance of the link between irrigation and farm productivity in a context of rising water scarcity, there is a lack of rigorous assessments of the impact of irrigation projects generally and in rice farming in particular. Furthermore, evidence focused on efficiency impacts based on SPF models is nearly nonexistent (Njuki and Bravo-Ureta 2018; World Bank 2011). This chapter adds to this slim literature and aims to inform future projects and policies by evaluating the impact of IRPEP on the productivity of smallholder farmers in the Philippines. We use state of the art SPF methodologies within an impact evaluation framework to measure the project's impact on two key productivity components: 1) Technological change captured by a shift in the frontier; and 2) TE differentials between IRPEP beneficiary (treated) and non-beneficiary (control) groups.

The rest of the chapter is organized as follows. Section 3.2 provides a brief discussion of key features of IRPEP followed by a review of the related literature in Section 3.3. We then present the methodology in Section 3.4, followed by the data and the empirical model in Section 3.5. Section 3.6 contains the results and the final section offers a summary and concluding remarks.

3.2 Context

Agriculture in the Philippines, which is dominated by smallholder farming, generates around 11 per cent of national income and provides livelihoods for 30 per cent of the population (OECD 2017). In rural areas, about 70 per cent of the population is poor and heavily reliant on agriculture, chiefly rice farming. Rice is the most important source of calories (46 per cent) and of protein (34 per cent) (WFP 2017).

There are serious concerns over the competitiveness of rice production in the Philippines, evidenced by high import rates from countries such as Thailand and Vietnam (Dawe 2006; Bordey et al. 2016). This reliance on imports is partially linked to low productivity, with the paddy yield in the country averaging around 3.99 t/ha., much lower than other countries in the region such as China (6.75 t/ha.) and Vietnam (5.75 t/ha.) (Ricepedia 2017; GRiSP 2013). Consequently, increasing the productivity and production of rice is a key strategic policy aim (Bordey et al. 2016; NEDA 2017). To this end, the National Irrigation Authority has made substantial investments to upgrade irrigation systems, but the success of these efforts is unclear and a sizeable share of irrigable land (around 41 per cent) has not benefited from such investments (Inocencio et al. 2016; PSA 2016). As a result, improving irrigation coverage to enhance productivity, and thus promote rural transformation, remains a key aim of the Philippines Development Plan 2017-2022, with small-scale communal irrigation the preferred instrument for reaching smallholders (NEDA, 2017a).

IRPEP aimed to unlock the production potential of smallholder rice farmers in the Philippines by rehabilitating the canal infrastructure of CISs, mainly in the form of concrete-lining to reduce seepage, in order to improve the quality and coverage of water delivery. The project also strengthened the capacity of IAs in order to improve the management, maintenance and leadership of the CIS in a sustainable manner (Bagadion and Korten 1991; Hamdy et al. 2009). More reliable, efficient, timely and equitable water availability as a result of IRPEP activities was anticipated to increase cropping intensity and productivity (particularly during the dry season), to improve labor efficiency and reduce susceptibility to pests (IFC 2003). Combined with FFS based on the PhilRice Palay Check System, plus marketing support, increased rice productivity was expected to translate into increased household output and income from crop sales, as well as improved food security and nutrition (Bhattarai et al. 2002; Godfray et al. 2010; Knox et al. 2013).

In this paper we focus on IRPEP's impact on beneficiaries' production frontier and their TE. The shift in the frontier is expected to arise from the technology improvements in irrigation, while TE improvements are expected from project activities intended to strengthen managerial performance, such as the FFS and the capacity building of IAs who can then provide management support to the CIS users. In addition, TE may be improved by complementarities between irrigation and other inputs (which was a key aspect of the Green Revolution), and also through farmers deciding to invest more in improving their managerial performance due to the greater reliability provided by improved water supply (Evenson and Gollin 2003; Hazell 2009; Gebregziabher et al. 2012).

3.3 Related literature

This study combines methods from two strands of the literature related to rice farming: studies on the relationship between irrigation and TE, and rigorous impact evaluation studies of irrigation projects for rice farmers.

The analysis of TE using frontier function methodologies has been a dynamic area of research in production economics and an extensive literature has evolved focusing on agriculture (Bravo-Ureta et al. 2007 and 2017). In applied work, the most common approach to measuring TE is the gap between observed and potential output that could be produced relative to a reference “best practice” frontier (Greene 2008; Coelli et al. 2005). The estimation of best practice frontiers to derive TE measures can be done with different methods, and here we focus on the studies using SPF models to examine TE in rice farming, which is the approach we implement below (Fried et al. 2008).

Findings from the existing SPF studies focusing on irrigation and TE in rice farming are mixed. In the Philippines, for instance, Yao and Shively (2007) applied a Cobb-Douglas SPF to a panel data sample of 747 parcels (irrigated and rainfed) and found a positive correlation between irrigation and TE. Similarly, in Tanzania, Mkanthama et al. (2018) applied a translog SPF to a sample of 68 irrigated and 74 rainfed plots and estimated that the average TE for irrigated plots was 96 per cent, compared to 29 per cent for rainfed plots. In a study of rice farmers in Ethiopia, however, Makombe et al. (2017) applied a translog SPF to a sample of 248 farmers with irrigated and 319 with rainfed land and reported that the average TE was higher for those with rainfed land (78 per cent vs. 71 per cent). In addition, in Bangladesh, Rahman (2011) applied Green's (2010) sample selection SPF along with a translog model to a sample of 946 rice farmers and found an average TE of 82 per cent.

There are many factors that could potentially influence the link between irrigation and TE of rice production. For instance, the same study in Tanzania also found that the high TE of irrigated plots was linked to adoption of high yielding seed varieties (Mkanthama et al. 2018). This mechanism relies on access and affordability of such complementary inputs which farmers from the studies in Ethiopia and Bangladesh may have lacked. Knowledge of water management may also be a mitigating factor. This is highlighted by a study in Tamil Nadu in India, which applied a translog SPF to a sample of 224 rice plots and found that the relatively low TE of the irrigated plots (63 per cent) was partly due to low Irrigation Water Efficiency, which was estimated at 34 per cent (Kuppannan et al. 2017).

The equality of water distribution within the irrigation systems may also influence the relationship between irrigation and TE. In the same study from the Philippines, it was found that water was not distributed evenly along the irrigation canals due to poor administration, meaning that the benefits to TE were unequally distributed (Yao and Shively 2007). In such cases, the average TE may suffer as a result of this inequality. Given that unequal water distribution is particularly an issue for canal irrigation projects such as IRPEP (Fujiie et al. 2005; Kakuta 2017), we conduct additional tests for impact in this chapter, as with the previous chapter, according to location on the irrigation canal.

Although impact evaluation as a subfield of research has grown very quickly, few impact evaluations have been conducted on irrigation projects, especially those that focus on rice production (World Bank 2011; Cameron et al. 2016). The existing impact evaluation literature on irrigation projects is dominated by quasi-experimental methodologies, including studies that rely only on cross-sectional data and utilize PSM with limited or no attention given to selection bias from unobservables.

The existing studies that focus on rice production invariably find positive impacts on rice yields. In the previous chapter focusing on the same project, we find positive impacts on yields of 13 per cent and eight per cent for Regions VI and X, respectively. Another large-scale canal irrigation project in Region VI was also found to have improved rice yields by around 50 per cent, as well as the use of chemical fertilizer and hybrid seeds (JICA 2012). Using a PSM methodology, an irrigation infrastructure project in Madagascar (which also promoted land tenure security and use of improved seeds) was found to have significantly improved rice yields by around 25 per cent (Ring et al. 2018). Similarly, using a Difference in Difference methodology, a large-scale canal irrigation project in Andhra Pradesh, India was found to have increased rice yields by up to 66 per cent, while a smaller-scale canal irrigation project in Ghana, analyzed using a PSM methodology, was found to have increased rice yields by 1.1 t/ha. (World Bank 2008; Kuwornu and Owusu 2012). As also noted in the review of the TE literature above, issues of water equality were detected in the impact evaluation studies in India and the Philippines (World Bank 2008; JICA 2012).

The only known irrigation study that combines TE and impact evaluation methods is that of Gebregziabher et al. (2012), though it is not related to rice production. With a sample of 426 irrigated and 1,768 rainfed plots located in the Tigray region of Ethiopia, the authors first use PSM to create a matched sample of treated and control plots and then estimate Cobb-Douglas SPF models following the Battese and Coelli (1995) framework. Their approach, however, does not address possible selection bias from unobservables and does not test for potential technology differences between irrigated and rainfed farming. Consistent with the impact evaluation studies mentioned above, the authors find that agricultural productivity was higher on the irrigated plots; however, the average TE for irrigated plots was just 45 per cent compared to 82 per cent for rainfed plots.

Both of these strands of the literature have shortcomings that we address in this paper. The existing TE studies provide inconclusive evidence of the link between irrigation and TE in rice production. Although the mixed findings of these studies may be driven by differing contextual factors, the absence of rigorous comparisons between irrigated and non-irrigated plots, does not make it possible to assess whether these results are biased and thus misleading due to selectivity. For instance, better farm managers may be richer and more motivated to use irrigation, meaning that without an adequate counterfactual it is not possible to ascertain the degree to which the higher productivity or TE of irrigated plots is attributable to irrigation or to unobserved farmer characteristics.

On the other hand, while addressing the selection bias issue, the impact evaluation studies only focus on rice yields, without considering TE. As the findings from the study by Gebregziabher et al. (2012) show, productivity can be improved without an increase in TE, meaning that irrigation projects may expand the production frontier and improve yields, but leave beneficiaries producing far below their production potential. Therefore, assessing both technology effects and TE provides a more detailed picture of the mechanisms through which irrigation affects productivity, and thus provides richer implications of the package of technology and management support that future projects should provide in a given context to maximize impact. In this paper, we apply the most robust known analysis to achieve this goal, using sample selection bias-corrected SPF frontiers to identify separately a project's technology effect and TE differentials across suitably matched groups of treated and control plots. A comparison across the two groups is then undertaken based on a common benchmark estimated with a Stochastic Meta-Frontier (SMF) model.

3.4 Methodology

Our aim is to identify separately production technology induced effects and TE differentials associated with improved irrigation infrastructure and to this end we employ the approach by Bravo-Ureta et al. (BGS) (2012). Unlike in the literature reviewed above, this framework corrects for biases from both observables (using matching methods) and unobservables (by implementing Greene's (2010) selectivity corrected SPF model (SC-SPF)). BGS (2012) applied the SC-SPF model to investigate technology and TE gaps using an ex-post cross-sectional dataset for treated and control farmers originally collected to evaluate the MARENA Program implemented in Honduras. Subsequent applications of the BGS model include: González-Flores et al. (2014), who explored the impact of *Plataformas de Concertación* in Ecuador; Villano et al. (2015), who incorporated a deterministic meta-frontier (MF) to analyze the impact of adopting certified rice seed in the Philippines; De los Santos-Montero and Bravo-Ureta (2017), who also used a deterministic MF to examine the productivity effects of a natural resource management program implemented in Nicaragua (POSAF-II); Abdulai and Abdulai (2017), who studied the impact of conservation practices on the environmental efficiency of maize producers in Zambia; Lawin and Tamini (2019), who incorporated a SMF to examine the impact of land tenure security on TE in Benin; and Abdul-Rahaman and Abdulai (2018), who investigated the impact of farmer groups on yields and TE in Northern Ghana.

With the exception of Lawin and Tamini (2019), a clear shortcoming of the studies just cited as well as the TE studies discussed in Section 3.3, is the failure to estimate a meta-frontier to provide a benchmark technology required for valid performance comparisons across the groups under study. In what follows, we implement the BGS (2012) along with the SMF approach of Huang et al. (2014) to obtain a common benchmark technology. Hence, we are able to conduct a rigorous analysis of the impact of IRPEP including meaningful technology and TE comparisons between project beneficiaries and control farmers.

The methodology we utilise entails the following steps: 1) Estimation of a binary project participation model to obtain Propensity Scores; 2) Use of PSM to define a sample of beneficiary and treated parcels that are as similar as possible based on observable baseline attributes; 3) Estimation of separate SC-SPF models for control and beneficiary parcels to deal with biases from unobservables; and 4) Estimation of an SMF model that makes it possible to make valid comparisons between the performance of beneficiary and control groups vis-á-vis a common benchmark technology.

In this paper, we estimate a probit participation model at the parcel level to generate Propensity Scores representing a parcel's probability of being treated, i.e. receiving IRPEP support (Khandker et al. 2010; Cameron and Trivedi 2005). Once the Propensity Scores are generated, we discard observations that do not fulfil the common support condition (Heinrich et al. 2010). The remaining parcels are the basis for a second round of sample adjustment to improve the balance of the treatment and control groups, where balance refers to the similarity of treated and control parcels according to the variables included in the participation model. We test for balance using the standardized percentage bias for each covariate, which is the mean of the treated group minus the mean of the control group divided by the average of the square root of the variance of the treatment and control samples (see Austin and Stuart 2015; Rosenbaum and Rubin 1985).

Several models are available to generate treated-control groups that are comparable (on observables) and it is common practice to implement alternative approaches so as to find better covariate balance and to assess whether results are consistent across different approaches. Here we employ two different approaches: (i) Radius matching which pairs all control parcels that fall within a predetermined PS value, or caliper, and drops all units that do not have at least one match; and (ii) Inverse Probability of Treatment Weighting (IPTW) where all parcels are assigned a weight equal to the inverse of the PS and no units are dropped (Austin and Stuart 2015). Once the treated and control samples are defined, we check for balancing. [6]

Once the best matched samples are determined, and assuming that bias from unobservables is not an issue, the project's ATET can be calculated as (Khandker et al. 2010; Winters et al. 2010; Villano et al. 2015):

$$ATET = E(Y_1|D = 1) - E(Y_0|D = 0) \qquad (3.1)$$

where Y_1 and Y_0 are the average values of the indicator in question (e.g., value of farm output) for the treated and non-treated groups, respectively, and D is a dummy variable equal to 1 for treated units.

Our objective is to go beyond a measure of the $ATET$ by examining differences in the technology and in the managerial performance, captured by TE, between treated and control groups. The SPF framework is well suited to undertake these separate measurements, but we need to deal with bias from unobservables within the SPF structure (Bravo-Ureta 2014). To accomplish the latter, we rely on Greene (2010), which is an extension of Heckman (1979) to nonlinear models. Specifically, Greene (2010) considers sample selection in a SPF framework assuming that the

[6] Additional alternatives were tried before concluding that radius and IPTW perform better than the other methods tested.

unobserved characteristics in the sample selection equation are correlated with the two-sided error in the stochastic frontier. Following Greene (2010), the model is written as:

Sample selection: $d_i = 1[\alpha' Z_i + w_i > 0], w_i \sim N(0,1)$ (3.2)

Stochastic frontier: $Y_i = \beta' X_i + \varepsilon_i \quad \varepsilon_i \sim N[0, \sigma_\varepsilon^2]$ (3.3)

(Y_i, X_i) are observed only when $d_i = 1$

Error structure:[7] $\varepsilon_i = v_i - u_i$ (3.4)

$u_i = \sigma_u |U_i|$ where $U_i \sim N(0,1)$

$v_i = \sigma_v V_i$ where $V_i \sim N(0,1)$

$(w_{i,} v_i) \sim N_2[(0,0), (1, \rho\sigma_v, \sigma_v^2)]$

The sample selection equation in (3.2) as well as the stochastic frontier in (3.3) are estimated twice, once assuming that *d* is equal to one for treated and zero for controls and then reversing the values for *d*; *Z* is a vector of explanatory variables; and w_i is an unobservable error term. Furthermore, *Y* is output, *X* is a vector of inputs in the production frontier and ε is the composed error term. In the stochastic frontier, β is a vector of parameters to be estimated and the error structure is 2-sided (normal)/1-sided (half-normal). As noted, sample selection in Greene's (2010) model arises when v_i, is correlated with w_i and this is captured by the term ρ in equation

[7] The normalisation of v_i and u_i in equation (3.4) is fully consistent with the expressions commonly used in standard stochastic production frontiers estimated with maximum likelihood procedures. The normalization is introduced to facilitate the estimation of the model parameters, which is done using maximum simulated likelihood (Greene 2010).

(3.4). If ρ is non-zero, then selectivity bias from unobservables is present. Details concerning estimation are available in Greene (2010) and Bravo-Ureta et al. (2012).

Another issue that needs consideration is whether the treated and control groups share the same technology because we are interested in comparing TE across the two groups. If the two groups do not share the same technology, then we need to estimate a standard benchmark of comparison. To generate this benchmark, we use the SMF model of Huang et al. (2014), which finds its origin in the deterministic MF model introduced by Battese and Rao (2002), and refined by Battese et al. (2004), and O'Donnell et al. (2008). The underpinning of the meta-frontier concept is that all units in the different groups (treated and control in this study), have access to different production technologies but each group uses a technology set depending on particular situations including: resource availability; human and financial capital; agro-ecological conditions; project participation status, being the key here, among others (O'Donnell et al. 2008). The advantage of the SMF is that it possesses statistical properties and has the ability to accommodate idiosyncratic shocks (Huang et al. 2014).

Following closely the exposition in Huang et al. (2014), the estimation of the SMF is done in two steps. In the first step, a separate SPF is estimated for each group (treated and control in our case), which can be represented by:

$$Y_{i,g} = f_{i,g}(X_{i,g}, \beta) + V_{i,g} - U_{i,g} \qquad (3.5)$$

where $Y_{i,g}$ and $X_{i,g}$ are respectively, a scalar output and a vector of inputs, in logs, for the i^{th} unit (firm, farm or a parcel) in the g^{th} group; β is a vector of parameters to be estimated; V is the standard 2-sided normally distributed error and U the one-sided error denoting efficiency. The TE for the i^{th} unit in group g is given by $e^{-U_{i,g}}$.

Denoting the predicted values from the SPF estimates for group g from the first step as $f_{i,g}(X_{i,g}, \hat{\beta})$, the meta-frontier is written as:

$$\ln \hat{f}(X_{i,g}, \beta) = \ln f_{i,g}^{M}(X_{i,g}, \beta) + V_{i,g}^{M} - U_{g,i}^{M} \qquad (3.6)$$

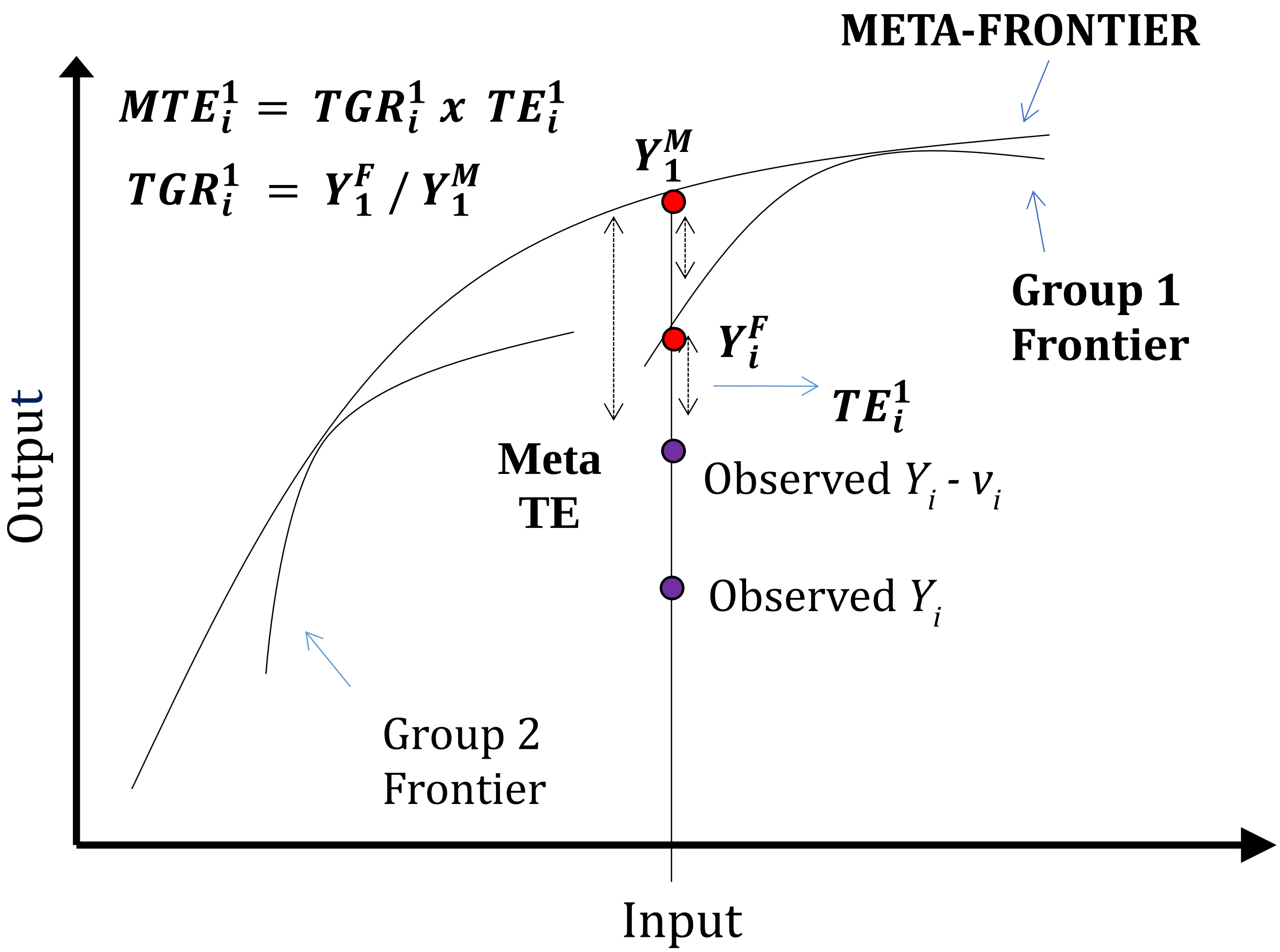
Equation (3.6) has the structure of a usual SPF model, where the last term is non-negative assumed to follow an exponential distribution. We underscore that the evidence indicates that results are robust with respect to different distributional assumptions for the one-sided term, and that the half-normal and exponential distributions are favored because of their relative simplicity (Kumbhakar and Lovell 2000; Coelli et al. 2005). In the second step, the predicted values for each group's frontier from the first step are pooled and then another SPF, which is the SMF, is estimated.

Figure 3.1 illustrates the connection between a unit's SPF and the SMF for a given level of input and associated observed output (Y_i). The observed output relative to the corresponding SMF can be decomposed into three elements: 1) The technology gap ratio (TGR_i^g), given by the unit's Frontier Output ($Y_{i,g}^F$) divided by the corresponding SMF output (Y_i^M), which arises from the choice of a particular technology and depends on how accessible the technology embedded in the SMF is to the individual groups and on the rate of technology adoption; 2) The unit's TE equal to observed output divided by Frontier Output (TE_i^g) given by $e^{-U_{i,g}}$; and 3) The random noise denoted by $e^{-V_{i,g}}$. Then, the estimated TE of the i^{th} unit in group g relative to the SMF, called meta-technical efficiency (MTE_i^g), can be written as:

$$\widehat{MTE}_i^g = \widehat{TGR}_i^g \times \widehat{TE}_i^g \qquad (3.7)$$

The *MTE* makes it possible to compare the TE of each group relative to the common SMF, while the *TGR* can be used to evaluate the position of each group's SPF with respect to the best available technology represented by the SMF.

Figure 3.1. Graphical illustration of the SPF and SMF



3.5 Data and empirical framework

We use the same household dataset as for Chapter 2, however we conduct the analysis at the parcel rather than household level. The sample is comprised of 714 treated parcels and 440 control parcels covering 1,000 households across 73 CISs, including 304 treated and 326 control parcels from Region VI, and 217 treated and 307 control parcels from Region X.

The household survey was designed to collect in-depth season and parcel level agricultural production data, along with socio-economic characteristics, covering the 12-month period preceding the data collection. The data spans two full cropping seasons and all agricultural variables are aggregated across both seasons. Hence, our focus is on the impact of IRPEP on annual production at the parcel level. This data was combined with high resolution (0.05°×0.05° degree) GIS-based rainfall data sourced from the Climate Hazards Group Infrared Precipitation and Station (Funk et al. 2015).

Table 3.1 presents descriptive statistics for key variables for the raw sample separately for the treatment and control groups. Results of t-tests between the means of the two groups reveal that the sampling design was effective at producing reasonably similar groups, thanks to the efforts taken to sample comparable treated and control groups explained in Chapter 2. However, differences in key variables, such as years of education of the household head, and the number of rooms in the house, a common indicator of wealth (Rutstein and Johnson 2004), highlight the need for additional steps to further improve balance.

Table 3.1. Descriptive statistics of original dataset, and for matched sample

	Treatment mean	Control mean	P-score	Treatment mean	Control mean	P-score	Treatment mean	Control mean	P-score
	Unmatched sample			*Matched sample – Radius*			*Matched sample - IPTW*		
Matching covariates									
Avg. age of all h'hold members	39.69	39.66	0.968	39.13	39.44	0.755	39.67	39.66	0.996
Years of ed. of h'hold head	8.50	9.16	0.007***	8.91	9.06	0.568	8.49	9.10	0.016**
Gender h'hold head (%)									
Female	14.01	15.23	0.567	13.56	14.25	0.761	13.94	14.93	0.648
Male	85.99	84.77		86.44	85.75		86.06	85.07	
Nr. adults in h'hold	3.13	2.97	0.063*	3.08	3.01	0.400	3.13	2.97	0.065*
Household size	4.30	4.18	0.314	4.29	4.24	0.715	4.30	4.19	0.358
Own home 2010 (%)	91.31	85.00	0.000***	91.32	87.71	0.068*	91.69	86.49	0.005***
Market distance (mins)	15.18	20.21	0.002***	15.40	16.83	0.372	14.96	17.42	0.095*
Assets 2010 (0-5 index)	1.41	1.34	0.198	1.32	1.33	0.895	1.41	1.34	0.231
Credit (%)	41.28	34.53	0.000***	37.37	34.88	0.004***	41.29	34.66	0.000***
Rainfall 2010 (mm)	3,522	3,100	0.000***	3,247.73	3,097.94	0.000***	3,525	3,090	0.000***
Other variables									
Farm size (ha)	0.94	0.93	0.880	1.01	0.88	0.044**	0.94	0.91	0.672
Total land cultivated (ha)									
Land owned (ha)	0.58	0.53	0.362	0.69	0.51	0.007***	0.58	0.51	0.250
Land rented (ha)	0.14	0.18	0.248	0.13	0.17	0.293	0.15	0.18	0.254
Parcel location (%)									
Upstream	20.73	15.91	0.021**	24.23	16.46		20.70	16.35	
Midstream	29.13	27.95		29.11	27.76	0.005***	29.15	27.73	
Downstream	50.14	56.14		46.66	55.78		50.14	55.92	0.060*
Total output (kg)	5,765	5,634	0.709	6,268	5,414	0.029**	5,787	5,580	0.562
Yields (kg/ha)	3,600	3,452	0.156	3,716	3,465	0.028**	3,615	3,465	0.155
Purchased inputs (PHP)	31,789	32,272	0.757	34,057	31,173	0.091*	31,791	32,301	0.748
Observations	714	440		553	407		710	422	

The next step is to estimate the participation model to generate Propensity Scores which are then used to verify the balance of the treatment and control samples at the parcel level. After dropping one treated and 16 control parcels whose Propensity Scores were out of the range of common support, we then applied radius matching and IPTW to define the samples to be used in the analysis. Table 3.1 also contains descriptive statistics for key variables for the two sets of treatment and control samples created by the radius and IPTW approaches.

Table 3.2 presents the reduction in the average magnitude of the standardized percentage bias achieved by the two matching approaches and the resulting sample sizes.[8] As shown in the table, the percentage bias for the unmatched treatment and control groups is around 17.5 per cent while after matching this percentage dropped significantly, particularly with the radius matching where the bias is 7.9 per cent. By contrast, the IPTW approach makes it possible to retain all parcels on common support for the analysis and reduces the associated bias to 10.1 per cent. These bias reductions reflect that both approaches yield well balanced samples (Austin and Stuart 2015).

Table 3.2. Standardized percentage bias and final sample size for Radius matching and IPTW

	Standardized percentage bias		**Final sample size *(units dropped)***	
	Before Matching	**After Matching**	**Treatment Sample**	**Control Sample**
Radius	17.5%	7.9%	556 *(157)*	409 *(15)*
IPTW	17.5%	10.1%	713 *(0)*	424 *(0)*

[8] A description of variables and results from the participation model are in the appendix in Tables 3.A.1 and 3.A.2. Graphs of propensity score distributions, before and after imposing common support, are in Figure 3.A.1. Table 3.A.3 contains a list of variable-specific reductions in standardized bias.

Having determined the final sample to be used in the analysis, we proceed with the estimation of alternative Cobb-Douglas SPF models, one for the treatment and one for the control group, using the following overall specification:[9]

$$\ln Y_i = \beta_0 + \sum \beta_j \ln X_{ij} + \sum \gamma_{ij} \ln F_{ij} + \sum \delta_j \ln H_{ij} + \sum \lambda_j \ln Z_{ij} + v_i - u_i \quad (3.8)$$

where Y_i is total rice production (kg) for parcel *i*; X_{ij} is the j^{th} traditional input used on the i^{th} parcel; F_{ij} comprises of three farm level variables; H_{ij} are five household attributes; and Z_{ij} are five environmental variables. All Greek letters are unknown parameters to be estimated; and v_i and u_i are the two sided and one-sided error terms, respectively.[10]

We use a log likelihood test to check the null hypothesis that the treated and control parcels share the same technology (De los Santos-Montero and Bravo-Ureta 2017). The test rejects the null hypothesis, which provides evidence that control and treated groups exhibit different technologies, supporting the need to estimate a MF.

The following step is to estimate the SPF models correcting for self-selection (SC-SPF) using the specification in equation (3.8) separately for treated and controls along with the selection model given by:

$$SELEC_i = \alpha_0 + \sum_{k=1}^{11} \alpha_{ik} CV_{ik} + w_i \quad (3.9)$$

where $SELEC_i$ is a binary variable for the treatment status of the i^{th} individual, CV_{ik} is a vector of exogenous covariates; α are the unknown parameters to be estimated; and *w* is an error term distributed as *N(0, 1)*.[11] The empirical specification of the *SELEC* model is in line with what is

[9] We use a Cobb-Douglas specification, which globally satisfies key regularity conditions from production theory. In contrast, the translog functional form, a commonly used alternative, does not satisfy such conditions at all data points and thus inevitably violates theoretical properties that can distort the empirical analysis (see O'Donnell 2012; 2016).
[10] Descriptive statistics for all variables used in the production frontier models appear in Tables A-4 and A-5.
[11] The SC-SPF models are estimated using the sample selection option in LIMDEP Version 11 (Greene 2016).

found in the literature (e.g., Lawin and Tamini 2019; De los Santos-Montero and Bravo-Ureta 2017; Villano et al. 2015; Wollni and Brümmer 2012).[12]

3.6 Results

3.6.1 Parameter estimates for SPFs, SC-SPFs, and the SMF

Table 3.3 presents the results for the conventional SPFs, the SC-SPFs and the SMF for the two data balancing approaches: (i) Radius matching; and (ii) IPTW. Overall, the parameter estimates are highly consistent across the six models shown. We note that the coefficients of the three traditional inputs (land, labor and purchased inputs) are positive and highly significant and, as expected from theory, have values greater than zero and less than one. Given the Cobb-Douglas specification, these coefficients are partial production elasticities and based on their values, land is the most important input, followed by purchased inputs and then labor. The sum of these partial elasticities, which provides a measure of returns to scale, ranges from 1.00 to 1.08 revealing constant to slightly increasing returns.

The signs of the parameters for the other variables included in the model are largely as expected, such as the positive signs for soil fertility, rainfall, household experience and education, FFS involvement and credit access, and the negative sign for weather shock exposure. The coefficients for tiller and seed transplanting are positive and significant only for the treatment group, which indicates that improved irrigation also enhanced the contribution of these inputs. As noted above, FFS were provided by IRPEP but also by the government to farmers across the country, so its coefficient refers to FFS in any form (not only those provided by IRPEP). The only unexpected

[12] A description of the variables used in the selection model and the results from the estimation are contained in Appendix Tables 3.A.1 and 3.A.6, respectively.

result is the negative sign for land ownership. One potential explanation is that land tenure is not secure in the study area due to weak enforcement of land ownership claims or risks of land appropriation (Fitzpatrick & Compton, 2014).

The results of the SC-SPFs reveal statistically significant selectivity bias when radius matching is used. Hence, these results along with the evidence of different technologies for the treated and control groups reported earlier support the use of the SMF framework. In addition, a simple inspection of the results reveals differences between the corresponding parameter values for the control and treated samples.

Table 3.3. Parameter Estimates for conventional and SC-SPF, and SMF models

	Conventional SPF				SC-SPF				SMF	
	Treatment		Control		Treatment		Control			
	(i) Radius	(ii) IPTW	(i) Radius	(ii) IPTW	(i) Radius	(ii) IPTW	(i) Radius	(ii) IPTW	(i) Radius	(ii) IPTW
Constant	3.190**	3.940***	3.796**	5.848***	2.967*	2.881***	4.381**	6.804***	3.194***	3.636***
Area	0.656***	0.659***	0.678***	0.558***	0.639***	0.582***	0.671***	0.588***	0.662***	0.578***
Labour	0.073***	0.070***	0.158***	0.159***	0.093***	0.122***	0.167***	0.162***	0.113***	0.117***
Purchased inputs	0.283***	0.303***	0.202***	0.295***	0.277***	0.373***	0.198***	0.250***	0.238***	0.359***
Tiller	0.232***	0.260***	-0.017	-0.022	0.235**	0.280***	0.034	-0.049	0.157***	0.158***
Improved seed	0.001	-0.047	0.080	0.052	-0.057	-0.082***	0.091	0.051	0.020***	-0.016
Transplant	0.128**	0.159***	0.076	0.100*	0.172***	0.235***	0.071	0.099	0.128***	0.201***
Owned parcel	-0.047	-0.041	-0.050	-0.056	-0.014	-0.036***	-0.026	-0.037	-0.018***	-0.027***
Soil fertility	0.081	0.097**	-0.000	-0.041	0.058	0.061***	0.002	-0.038	0.041***	0.016
Parcel location	0.080*	0.043	-0.070	-0.120**	0.076	0.044***	-0.086	-0.123**	0.029***	0.012
Rainfall	0.170	0.062	0.178	-0.140	0.227	0.125***	0.154	-0.190	0.258***	0.057***
Weather shock	-0.009	-0.067	0.130**	0.119*	-0.048	-0.098***	0.133*	0.138*	0.027***	-0.019
Experience	0.111	0.088	0.105	0.026	0.080	0.084***	0.057	0.051	0.068***	0.095***
Education	0.091***	0.082***	0.010	0.026	0.101***	0.096***	0.000	0.034	0.043***	0.058***
Credit	0.185	0.320	0.322	0.390*	0.287	0.404***	0.547*	0.570*	0.445***	0.707***
FFS	0.074*	0.062*	-0.001	0.001	0.090*	0.075***	-0.014	-0.028	0.057***	0.077***
Region VI	-0.260***	-0.288***	-0.190*	-0.234**	-0.264***	-0.257***	-0.242**	-0.273***	-0.265***	-0.302***
Rho					0.020	0.000	-0.531*	-0.351		
Observations	553	710	407	422	553/960#	710/1,132#	407/960#	422/1,132#	960	1,132

The first number is the sample size for the Probit model and the second for the SC-SPF.
*,** and *** indicate that the estimated coefficient is statistically significant at the ten, five and one per cent levels, respectively.

3.6.2 Predicted Frontier Output, TGR, TE and MTE

Table 3.4 presents predicted mean Frontier Output, TGRs and the TE values calculated from the SC-SPF and the SMF models for the treatment and control groups using the radius and IPTW samples. The mean Frontier Output calculated from the SC-SPF models for the treated is significantly higher (at the 1 per cent level) compared to controls for both the radius (9,680kg *vs.* 8,231kg) and the IPTW (10,900kg *vs.* 8,654kg) samples. In contrast, the mean TE scores are 61 per cent (treated) and 74 per cent (control) for the radius samples and this difference is significant at the 1 per cent level. The corresponding mean TE scores for the IPTW samples are 53 per cent and 65 per cent, again significant at the 1 per cent level.

As would be expected, the mean Frontier Output levels from the SMF are higher than those obtained from the SC-SPF models, as shown by the figures in columns 1 and 3 of Table 3.4. Specifically, for the radius samples the meta-frontier mean output for the treated is 14.7 per cent greater than controls (9,911kg *vs.* 8,642kg) and the corresponding number for the IPTW is 3.9 per cent (11,147kg *vs.* 10,717kg). We note that the mean difference for the radius sample is significant at the 5 per cent level while it is not significant for the IPTW sample.

Column 4 in Table 3.4 presents the mean TGR which is equal to a group's mean Frontier Output (column 1) divided by the corresponding mean SMF output (column 2). Consequently, the TGRs for the treated and control groups are 0.98 and 0.95 for the radius sample, and the corresponding values for IPTW are 0.98 and 0.81. The differences in mean TGRs are statistically significant in both cases (1 per cent).

The final set of numbers in Column 5 present the MTE which is given by the multiplication of the TE and TGR; thus, this indicator incorporates inefficiency gaps with respect to both the corresponding own group frontier and the SMF. For the radius sample, Table 3.4 shows a mean MTE equal to 59 per cent and 70 per cent for treated and control, respectively, and this amounts to an average gap equal to 15.7 per cent in favor of control farmers which is statistically significant (1 per cent). The figures for the IPTW samples are 52 per cent for treated and 54 per cent for controls and the difference is again significant (1 per cent) in favor of controls but with a narrower gap of 3.7 per cent.

These results reveal that beneficiaries exhibit a significantly higher average Frontier Output compared to the control group, a difference that is attributable to IRPEP. This result is consistent for samples generated with radius matching as well as IPTW, and for both the respective SPFs as well as the common SMF. Conversely, control farmers possess a TE advantage relative to beneficiaries, which is observed for all calculations presented in Table 3.4, although the magnitudes differ. In the case of both Frontier Output and MTE or TE, the difference between treated and control is smaller for the SMF model, which highlights the importance of using a common benchmark (i.e., the meta-frontier) to avoid distorted estimates of project impact.

This indicates that IRPEP enhanced the technology available to beneficiaries leading to an increase in their Frontier Output, but did not contribute to improving managerial performance, which exerted a negative effect on MTE. IRPEP was designed to improve both the technology and managerial ability (thereby MTE) of beneficiaries through the strengthening of IAs, so they could be in a better position to support their members. The project was also expected to improve TE through more effective FFS relative to what was available from the government to all farmers in the country. In analyzing the impact of an agricultural support project for small-scale potato farmers in Ecuador, González-Flores et al. (2014) attribute a lack of impact on TE to farmers still being in the “learning by doing” stage. Based on this, another possible factor here is that the full impact of IRPEP might take additional exposure to be fully absorbed by beneficiaries, with TE and MTE increasing over time as farmers adjust their managerial performance to the new technology.

Table 3.4. Predicted mean Frontier Output and TE values calculated from the SC-SPF and the SMF models for the Radius and IPTW samples.

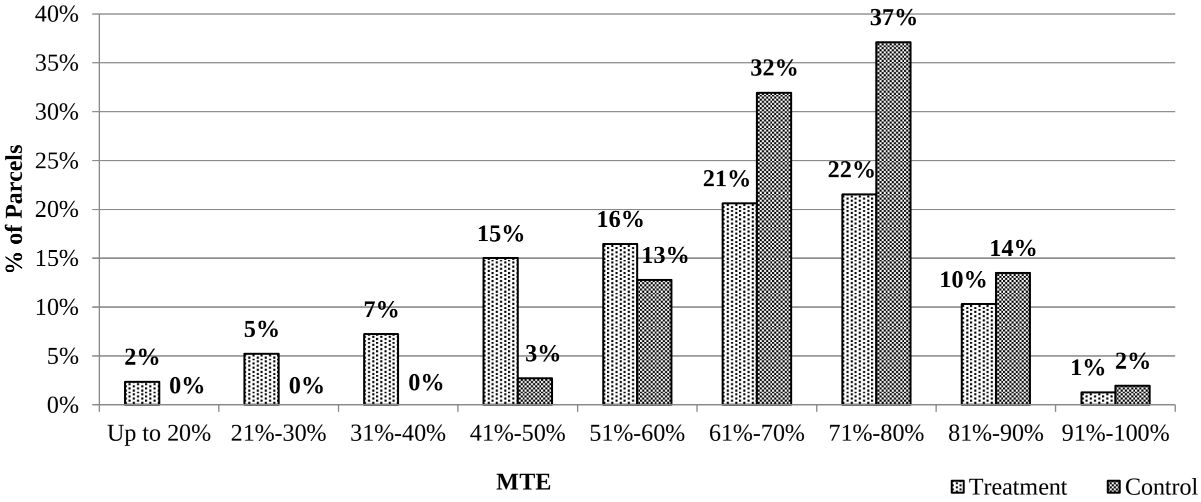
	Output SC-SPF -1-	TE SC-SPF -2-	Output SMF -3-	TGR -4-	MTE -5-	Obs. -6-
(i) Radius						
Treatment mean	9,680	0.61	9,911	0.98	0.59	553
Control mean	8,231	0.74	8,642	0.95	0.70	407
Difference	17.6%	-17.6%	14.7%	3.2%	-15.7%	
P-score	0.008***	0.000***	0.022**	0.000***	0.000***	
(ii) IPTW						
Treatment mean	10,900	0.53	11,141	0.98	0.52	710
Control mean	8,654	0.65	10,717	0.81	0.54	422
Difference	25.9%	-18.5%	3.9%	15.5%	-3.7%	
P-score	0.000***	0.000***	0.502	0.000***	0.013**	

3.6.3 Distribution of MTE

Graph 3.1 presents the distribution of the MTE values for the treatment and control groups. For both groups, the largest percentage of parcels have an MTE between 71-80 per cent, but a higher proportion of control parcels have MTE scores in the 81-90 per cent and the 91-100 per cent brackets. There are 14 per cent of treated parcels with an MTE below 40 per cent, whilst no control parcels have an MTE below 40 per cent.

The different distributions between the treated and control parcels are clearly linked to the findings presented in Table 3.4. Specifically, given that the frontier for treated parcels has expanded, the larger shares of these parcels in the lower brackets highlight lagging TE with respect to the higher frontier. The distribution of the control parcels represents how treated parcels would have fared without the increase in the frontier, showing that TE was reasonably high before the impact of IRPEP. This may be due to the project's targeting of CISs with high potential for increasing their productivity through the provision of improved technology and may also be linked to the widespread provision of FFS by the Philippines government.

Graph 3.1. MTE distribution for treatment and control parcels



3.6.4 Observed and predicted yields and gross margins

Table 3.5 presents observed and predicted mean yields and gross margins for the average and the frontier farmer based on the radius samples. Above we noted that IRPEP was effective in increasing rice frontier production of beneficiaries, but no improvement was observed for TE; thus, the MTE is lower for the treated compared to the controls. The data in Table 3.5 provides a further assessment of the impact of IRPEP on production based on predicted values from the SMF benchmark. The first row in Table 3.5 shows that observed yields (measured in kg/ha) for farmers matched with the radius approach are 3,716 for treated and 3,465 for control farmers—echoing the findings from Chapter 2. However, predicted yields for the average farmer are 3,516 for treated and 3,865 for controls. In contrast, predicted yields for the frontier farmer are higher (5,902) for the treated than the controls (5,509). All of these yield differentials are statistically significant as revealed by the values in the last column of Table 3.5.

Focusing on the gross margins presented in the second half of Table 3.5, we see an overall pattern that is similar to the results for yields, but only the difference for the predicted average farmer is statistically significant. In short, these figures confirm the benefits that IRPEP had on treated farmers due to an upward shift in the production frontier relative to the control group and reflect the converse impact of the project on MTE and TE. This latter finding is compatible with the empirical results reported by González-Flores et al. (2014) for potato farmers in Ecuador and by Sipiläinen and Lansink (2005) for Finnish dairy farmers. Moreover, these results are consistent with the theoretical proposition that technological change disrupts the prevailing farm equilibrium preceding that change (Schultz 1975). Building on the proposition, which asserts that education is a key component in overcoming disequilibria effects, our results also indicate that more emphases on training could have led to favorable impacts on MTE.

Table 3.5. Observed and predicted mean values for key outcome variables of yields (kg/ha) and gross margins (PHP/kg) for the Radius samples

	Treatment mean	Control mean	Difference	P-score
Yields (kg/ha)				
Observed	3,716	3,465	-7.2%	0.028**
Predicted-Average farmer	3,516	3,865	-9.0%	0.000***
Predicted-Frontier farmer	5,902	5,509	7.1%	0.000***
Gross Margins (PHP/kg)				
Observed	10.18	10.22	-0.4%	0.889
Predicted-Average farmer	10.55	11.98	-11.9%	0.000***
Predicted-Frontier farmer	13.79	13.68	0.8%	0.224

3.6.5 Heterogeneity analysis

As is shown in Table 3.3, numerous factors play a significant role in shaping rice production within the sample. Therefore, Table 3.6 presents an analysis of possible heterogeneity in the project impact on mean Frontier Output across several key variables using the results from the SMF model with the radius sample. The table presents t-tests of mean outcomes of treated versus control groups for different sub-samples separated by key variables of interest. Using SMF values, the analysis indicates that gender and education of the household head, regional location, farm size and parcel location along the canal are all associated with project impact.

First, we find that the project had a significant impact (at the 5 per cent level) on Frontier Output for treated male-headed households compared to control male-headed households, but this pattern is not observed for female-headed households. This suggests that potential barriers faced by rural women and female-headed households—including higher poverty, lower access to productive assets and capital, higher workloads and constraining social norms (World Bank, 2012)—likely prevented them from taking advantage of project benefits. Although the project targeted women by encouraging them to enter into management positions within IAs—something that we find in the previous chapter to have been successful—our findings indicate that this support may have mainly benefitted women who live in male-headed households. Looking further into the IRPEP data, we find that female-headed households were less likely to be an IA member or to use IA facilities.

Second and surprisingly, we find a significant impact (at the 1 per cent level) on the mean Frontier Output for household heads with education below the median level for the sample, but not so for those with education above the median level. This may be due to a higher involvement of more educated household heads in off-farm activities, which would leave less time for them to engage effectively with the project and thus obtain benefits in terms of rice production.

Third, we find stronger evidence of project impact on mean Frontier Output for households in Region VI compared to Region X. Given that Region VI has much lower starting yields, this finding suggests that the marginal effect of irrigation on the frontier is stronger at lower productivity systems, while other complementary support becomes essential in higher productivity systems.

At the parcel level, we find that size and location on the irrigation canal are important in terms of productivity. Specifically, smaller farms (defined as those below the median farm size) and those located downstream on the canal experienced a significant impact (at the 5 per cent and 1 per cent levels respectively) on Frontier Output, while larger farms and those located up or midstream did not. This offers a nuanced finding to Chapter 2, where we find that the impact on yields was similar for down and upstream households. Smaller farms and downstream farms are both associated with lower production and higher levels of poverty—as reflected by the lower mean predicted output for these groups. Similar to the regional results discussed above, these findings suggest that starting from a lower output may have increased the project's potential impact thus being relatively more beneficial to poorer beneficiaries.

The results for downstream parcels suggest that IRPEP has succeeded in improving water equity, echoing the findings in Chapter 2. As noted, downstream parcels usually suffer the most from poor irrigation access due to overuse by parcels located further up the canal (Lebdi 2016). As discussed in Chapter 2, qualitative interviews found that improved water equity for downstream parcels was achieved thanks to the improved canal infrastructure making more water available through improved efficiency, as well as improved capacity of IAs to monitor and manage water use to ensure equitable distribution (Arslan et al. 2018)

IRPEP's impact on Frontier Output did not differ markedly between owned and rented parcels, although owned parcels have higher mean output as expected. There are a number of potential beneficial interactions between land ownership and the impact of development projects (Higgins et al., 2018). The aforementioned issues with tenure enforcement may have weakened these potential linkages in the case of IRPEP.

We performed the same heterogeneity tests for project impact on TE (data not shown). However, we found very little variation in the mean scores based on either the SC-SPF or the SMF, indicating that regardless of the sub-group, the means for control farmers were significantly larger than for the treated group. Interestingly, however, we find that the mean difference in TE is noticeably smaller for male-headed households compared to female-headed, and for downstream compared to up- and mid-stream parcels. These differences, combined with the findings for mean Frontier Output, suggest that the TE gap created by the project in favor of the control was less pronounced for male-headed households and for downstream parcels.

Table 3.6. Heterogeneity analysis based on Radius matching and SMF estimates: Output and yields

	Frontier Output (kg) from SMF Estimates		
	Treatment mean	**Control mean**	**P- score**
1) Gender of household head:			
Male	9,969 (478)	8,617 (349)	0.023**
Female	9,548 (75)	8,796 (58)	0.627
2) Education of household head:			
Below median	10,385 (266)	8,234 (186)	0.009***
Above median	9,473 (287)	8,987 (221)	0.518
3) Region:			
Region VI	6,312 (237)	5,389 (218)	0.089*
Region X	12,612 (316)	12,395 (189)	0.801
4) Farm size:			
Below median	4,029 (267)	3,652 (212)	0.014**
Above median	15,403 (286)	14,068 (195)	0.111
5) Parcel location:			
Up/midstream	10,807 (295)	10,568 (180)	0.787
Downstream	8,888 (258)	7116 (227)	0.008***
6) Land:			
Owned	10,438 (353)	9,344 (226)	0.149
Not owned	8,982 (200)	7,767 (181)	0.127

Note: Number of observations in parentheses

3.7 Conclusions

This chapter contributes to two strands of the literature by applying an SC-SPF model in an impact evaluation framework. We use parcel level data collected from beneficiaries and non-beneficiaries of IRPEP to assess the impact of small-scale irrigation improvements, together with support to IAs, on production technology and TE.

Based on predicted mean output and observed mean yields, we find that IRPEP significantly expanded the rice production frontier and improved rice productivity for beneficiaries. However, project beneficiaries exhibited lower TE, echoing findings of a previous study in

Ethiopia (Gebregziabher et al., 2012). This lower TE is also reflected in the observed and predicted gross margins of the sample. In summary, the project seemingly targeted poor but reasonably efficient rice farmers while providing technology that successfully improved the production potential of beneficiaries. However, no TE improvement of beneficiaries relative to controls is found. The latter is likely due to a lack of managerial support to stimulate complementarity activities, and/or adequate help to overcome the disequilibria caused by improved access to irrigation, leaving beneficiaries unable to take full advantage of their expanded production frontier. Given the available data, it is not possible to determine if additional exposure to improved irrigation would in due time lead to better management performance.

Small-scale irrigation is the subject of substantial policy attention and investment in the Philippines, and many other developing countries. Broadly, our findings suggest that policies to increase communal small-scale irrigation coverage can contribute to development objectives relating to productivity and food security, which in-turn have implications for inclusive rural transformation. However, this package of support does not seem to have met the urgent need to increase production efficiency (measured by TE) for rice in the face of growing water scarcity. Our findings indicate several ways that future interventions can be adjusted in order to achieve this goal.

First, complementary training and better access to high quality inputs need to be provided to enhance overall productivity gains. The appropriate tailoring of FFS could help farm managers to make decisions that increase their efficiency despite input and capital constraints. A systematic review of the impact of FFS found that bottom-up participatory approaches are often the most effective (Waddington et al., 2014). This approach highlights the potential benefits of making the PhilRice Palay Check System curriculum more flexible and open to feedback from farmers. Echoing Chapter 2, our findings also suggest that future irrigation infrastructure interventions should improve the availability of credit to relax liquidity constraints thus enabling the adoption of complementary inputs (e.g. improved seeds and planting material). This latter point aligns well with Waddington et al. (2014) who found that improving access to finance alongside FFS can have a powerful effect on productivity.

Appropriate training is also important to overcome input access constraints by helping farmers to identify which inputs and practices deserve prioritisation. For instance, our results from the SC-SPF estimates indicate that irrigation is highly complementary with mechanical tillage, along with seed transplanting, suggesting that training and extension support should encourage farm managers to adopt these practices so as to augment productivity.

Impacts on productivity, as well as equality, can also be enhanced for future interventions by addressing barriers faced by female-headed households. Among IRPEP beneficiaries, female-headed households seem to have faced particular barriers to participating and benefitting from IAs. Therefore, future interventions need to boost the capabilities of local institutions to manage and implement projects with a clear goal of being inclusive and sensitive to the needs of participants from female-headed households.

How beneficiaries are targeted with this complementary support is also an important factor for future interventions that can be informed by our findings. We find that the support package delivered by IRPEP was most effective among poorer households with low yields, including those with smaller farms located downstream on the canals, while better off households with higher yields are more in need of the complementary support outlined above to achieve further improvements. The more favorable impacts for downstream parcels confirms the findings from the previous chapter, showing that this combination of infrastructure and institutional support can prove very effective at improving the water equity issues that are commonplace in canal irrigation systems.

In terms of future research, our findings highlight the value of a multi-faceted approach that enables the separate identification of the role of technology and TE on productivity, going beyond the usual focus on yields, which can inform future impact evaluation studies. Comparing parcels from various groups to a common benchmark allows us to properly account for technology and TE differentials. Also, by using PSM combined with the SC-SPF framework we address selection bias that may have affected previous TE studies. That our results run counter to past studies on irrigation and TE in rice farming, which do not use a common benchmark to evaluate productivity, suggests that such studies may have generated misleading comparisons.

Appendix 3.A

Table 3.A.1. Description of variables included in the Probit models

Variable name	Description
Household characteristics	
House experience	Average age in household
Head experience	Age of household head
Education	Number of years of education of household head
Gender	Gender of household head
Number of adults	Number of adults (18+) in household
House size	Number of rooms in household in 2010
House ownership	Dummy: House was owned in 2010
House rooms	Number of rooms in house in 2010
Large livestock	Number of large livestock owned in 2010
Family workforce	Number of economically active household members in 2010
Social capital	Number of groups of which household is a member in 2010
Market distance	Distance from household to market (mins)
Assets	Household 2010 asset index
Credit	Proportion of households in municipality who accessed loan 2016
Parcel characteristics	
Owned parcel	Dummy: Parcel is owned
Owned parcel upstream	Dummy: Parcel is owned and is located upstream from irrigation source
Owned parcel midstream	Dummy: Parcel is owned and is located midstream from irrigation source
Environmental factors	
Rainfall 2010	Total rainfall in 2010 (mm)
Drought	Number of droughts experienced by household since 2010
Flood	Number of floods experienced by household since 2010

Table 3.A.2. Results of Probit participation model

Variables		Coefficient	Std. error
Constant		-1.854	0.760
House experience		-0.000	0.004
Head experience		-0.021	0.014
Gender		-0.033	0.110
Nr. adults		0.065	0.045
House size		-0.062	0.045
Home ownership		0.369**	0.157
Market distance		-0.007**	0.003
Assets		0.000	0.058
Credit		2.199*	1.272
Owned parcel upstream		0.332**	0.167
Rainfall 2010		0.000	0.000
Nr. Observations	1,154		
Log-likelihood function	-683.83		
Chi-squared test statistic	30.55		

Table 3.A.3. Change in standardized percentage bias for all balancing covariates

Variable	Raw	Radius matching	IPTW
House experience	-0.2	-2.3	13.8
Gender	-3.5	-2.7	8.0
Education	-16.3	-3.2	-10.5
Nr. adults	11.3	6.0	2.4
House size	-10.4	-3.2	-3.1
Home ownership	20.1	11.2	-4.6
Market distance	-18.6	-5.5	-0.01
Assets	7.8	-0.8	10.7
Credit	47.5	18.9	19.0
Owned parcel upstream	2.9	8.4	2.7
Rainfall 2010	54.2	24.6	-35.8
Average magnitude	17.5	7.9	10.1

Table 3.A.4. Description of variables included in the production frontiers

Variable name	Description
Inputs (all tallied across seasons)	
Area	Total area cultivated with rice crops
Labor	Number of family and hired labor days use during production process
Purchased inputs	Sum of expenditure on seeds, fertilizer, pesticides, herbicides and insecticides (PHP)
Tiller	Dummy: Tiller was used on parcel
Improved seed	Dummy: Seeds on parcel were hybrid/certified
Transplant	Dummy: Seeds on parcel were transplanted
Parcel characteristics	
Owned parcel	Dummy: Parcel is owned by household
Soil fertility	Dummy: Household reported that soil on parcel is moderate-very fertile
Parcel location	Dummy: Parcel is located downstream from irrigation source
Environmental factors	
Rainfall	Total rainfall in 2016 calendar year (mm)
Weather shock	Dummy: Household reported experiencing a drought, typhoon or flood during 2016
Household characteristics	
Experience	Age of household head
Education	Number of years of education of household head
Credit	Proportion of households in municipality who accessed loan 2016
FFS	Dummy: Household reported engaging in a Farmer Field School at least once between 2010-2016
Region VI	Dummy: Household located in Region VI

Table 3.A.5. Descriptive statistics of variables included in the production frontiers

	Treatment		Control		
	Mean	**Std. Deviation**	**Mean**	**Std. Deviation**	**P-score**
Area	1.64	1.61	1.71	1.59	0.494
Labour	51.81	41.99	52.68	43.07	0.736
Purchased inputs	20,226	16,922	19,604	16,460	0.540
Tiller	0.93	0.25	0.95	0.22	0.234
Improved seed	0.77	0.42	0.71	0.45	0.023**
Transplant	0.40	0.49	0.36	0.48	0.104
Owned parcel	0.58	0.49	0.55	0.50	0.257
Soil fertility	0.86	0.35	0.87	0.34	0.568
Parcel location	0.50	0.50	0.56	0.50	0.048**
Rainfall	3,164	528	2,695	512	0.000***
Weather shock	0.47	0.50	0.45	0.50	0.347
Experience	57.15	11.97	57.23	13.53	0.912
Education	8.50	3.90	9.16	4.35	0.007***
Credit	0.41	0.14	0.35	0.14	0.000***
FFS	0.29	0.45	0.25	0.43	0.186
Region VI	0.55	0.50	0.53	0.50	0.527
Observations	714		440		

Table 3.A.6. Results of the Probit selection model

i. Radius (N=960)

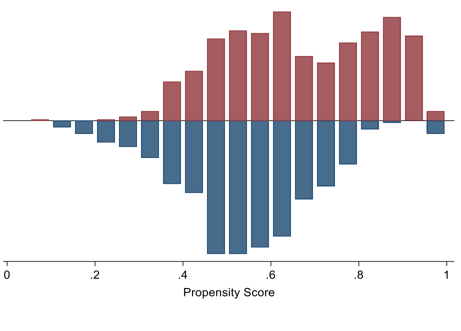
Variables	Coefficient	Std. error
Constant	-0.540	0.365
House experience	0.007	0.005
Head experience	-0.011*	0.006
Head education	-0.016	0.011
Gender	0.011	0.126
House size	0.060*	0.033
Home ownership	0.227	0.144
House rooms	-0.053	0.047
Large livestock	0.071***	0.020
Family workforce	-0.045	0.060
Social capital	-0.033	0.067
Assets	-0.015	0.054
Credit	2.129***	0.386
Market distance	-0.002	0.002
Owned parcel	0.183*	0.108
Owned parcel upstream	0.161	0.138
Owned parcel midstream	0.104	0.132
Drought	0.147***	0.039
Flood	-0.229***	0.056
Log-likelihood function -611.627		
Chi-squared test statistic 85.299		

ii. IPWRA (N=1132)

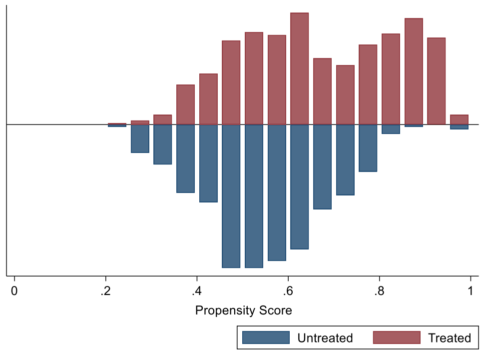
Variables	Coefficient	Std. error
Constant	-0.951***	0.350
House experience	0.006	0.005
Head experience	-0.009	0.005
Education	-0.026**	0.011
Gender	0.030	0.119
House size	0.062**	0.031
Home ownership	0.354***	0.135
House rooms	-0.084**	0.043
Large livestock	0.071***	0.019
Family workforce	-0.019	0.057
Social capital	0.004	0.064
Assets	0.000	0.050
Credit	3.426***	0.355
Market distance	-0.006***	0.002
Owned parcel	0.143	0.103
Owned parcel upstream	0.202	0.136
Owned parcel midstream	0.157	0.128
Drought	0.143***	0.038
Flood	-0.218***	0.054
Log-likelihood function -666.191		
Chi-squared test statistic 162.819		

Figure 3.A.1. Propensity score distribution before and after imposing common support

Before



After



Chapter 4

How can climate resilient infrastructure stimulate inclusive rural transformation?

Evidence from southwest Bangladesh

Abstract: Using a tailored framework of indicators, we assess the impact of climate resilient infrastructure on inclusive rural transformation. We find positive impacts on climate resilience, agricultural profitability, and off-farm advancements, for all but the poorest households. Income and income diversification progressed for the poorest households, but they faced barriers to off-farm advancements. The project had limited impacts on farm yields, self-employment, social indicators and women's empowerment. Limited impacts on asset ownership also meant that vulnerability to non-climatic shocks remained high. Living close to both an improved market and road helped to improve social capital, especially for women.

This chapter is based on:

Higgins, D., Arslan, A. and Ruben, R. *Can climate resilient infrastructure stimulate inclusive rural transformation? Evidence from southwest Bangladesh.* Working Paper

Currently under review by the Journal of South Asian Development

4.1 Introduction

Without climate resilience, increasingly intense climatic stressors have the potential to derail inclusive rural transformation pathways, especially for the poorest rural households (IFAD, 2018b). The aim of this chapter is to provide practical insights to inform future rural development initiatives aiming to stimulate sustainable transformational progress in areas of climate vulnerability.

We focus on how upgraded rural infrastructure—specifically climate resilient markets and market-connecting roads—can address this development challenge. Improved markets and roads have numerous potential impacts in this regard, including improving on- and off-farm livelihood opportunities, land and labour productivity, human capital and asset ownership, and can facilitate alternative economic engagement by marginalised groups, including women (World Bank, 1994; Bryceson et al., 2008; Jouanjean, 2013). Moreover, when designed to withstand exposure to climatic stressors, they can also increase climate resilience as part of the inclusive rural transformation process (OECD, 2018). We test these pathways using CCRIP southwest Bangladesh as a case study, using impact evaluation methods with a combination of quantitative and qualitative data.

Based on the findings of past studies, we focus on how impacts differ based on the type of infrastructure and beneficiaries' initial resource endowments. We do this using separate catchment areas to quantitatively assess whether households located close to both an upgraded market and market-connecting road benefitted more than households only located close to an upgraded market; and within these groups we assess whether landowners benefitted more than non-landowners. In both cases, we use in-depth qualitative data to understand impact mechanisms and reasons for impact heterogeneity.

The proceeding section of the chapter outlines the potential links between climate resilient infrastructure and inclusive rural transformation (Section 4.2), followed by a description of the project used as a case study (Section 4.3), the analytical methodology (Section 4.4), descriptive statistics (Section 4.5), results (Section 4.6), and the conclusions (Section 4.7).

4.2 Inclusive rural transformation, climatic stressors and infrastructure

The impacts of climate change and climatic shocks on livelihoods can hinder each of the components of rural transformation (Rickards & Howden, 2012; Carter et al., 2018; IFAD, 2018b). Floods, droughts, cyclones, changing rainfall patterns, and rising temperatures and sea levels can hinder agricultural production by damaging produce and farming assets (land, machinery, storage facilities) and disrupting growing seasons (Morton, 2007). They can also impede households from shifting into more lucrative livelihood activities by damaging other productive assets and infrastructure, thus reducing productive capacity and economic opportunities, and increasing vulnerability (Ahmed et al., 2009). By changing risk attitudes, increasing vulnerability and uncertainty, and reducing incomes, these effects—which disproportionately affect the most vulnerable—can also disincentivise investment in transformational livelihood activities (Mirza, 2003; FAO, 2017).

The potential impacts of improved rural markets and market-connecting roads on inclusive rural transformation are numerous, with varying levels of supporting evidence. Operational markets with quicker, cheaper and safer access can connect buyers and sellers of agricultural inputs and outputs, stimulating increased productivity, on-farm diversification and cash crop production (Gannon & Liu, 1997; van de Walle, 2009; Suri, 2011). Transaction costs can be reduced, improving access to value chains and options for selling produce, leading to higher prices and profits from farming (Banister & Berechman, 2003; Sieber & Allen, 2016; Devaux et al., 2018). These productivity and income benefits can in-turn drive rural transformation through labour reallocation and investment in higher-value activities (IFAD, 2016). These benefits have a large body of supporting evidence, covering projects in Afghanistan (Sieber & Allen, 2016), Bangladesh (Ali, 2011; Haider et al., 2011), China (Fan & Chan-Kang, 2005), Ethiopia (Wondemu & Weiss, 2012), India (Binswanger et al., 1993; Aggarwal, 2018), Nepal (Jacoby, 2000), Nicaragua (Broegaard et al., 2011), and Vietnam (Mu & van de Walle, 2007).

In terms of impacts on the climate resilience of agricultural production, better market access and higher farm income may enhance access to and adoption of resilience-enhancing inputs (Nelson et al., 2010). Climate resilient infrastructure can also help to avoid access to markets and other services being disrupted by climatic stressors, thus enhancing the resilience and sustainability of livelihoods and smoothing incomes (Ziervogel & Ericksen, 2010; Chongvilaivan et al., 2016). All-weather roads are the main focus of the existing literature, having been found to improve hybrid rice adoption in Bangladesh (Ali, 2011), decrease poverty and increase income in Ethiopia (Dercon et al., 2009; Wondemu & Weiss, 2012), and increase crop sales and income and decrease post-harvest losses in Uganda (Sieber & Allen, 2016).

Improved internal and external connectivity can also help to transform the composition of livelihoods by presenting new opportunities for households to capitalise on their comparative advantages (Asher & Novosad, 2016). These opportunities can include on- or off-farm wage employment or self-employment, or migration to cities, towns or other rural areas (IFAD, 2016; IIED, 2017). They may also help households to enter more lucrative agricultural or non-agricultural value chains and support specialisation (Reardon et al., 2007). This proliferation of options can subsequently reduce the vulnerability of livelihoods to climatic stressors through income diversification (Ellis, 1999; Füssel & Klein, 2006).

Empirical evidence suggests these potential livelihood composition impacts are heavily influenced by contextual factors. While upgraded rural roads have been found to increase off-farm opportunities in Indonesia (Gibson & Olivia, 2010), Peru (Escobal & Ponce, 2004), and

Vietnam (Mu & van de Walle, 2007), further studies find off-farm impacts to be dependent upon wealth and skills (Lokshin & Yemtsov, 2005; Bucheli et al., 2018), credit access (Aggarwal, 2018; Ahmed & Nahiduzzaman, 2016), proximity to urban centers (Asher & Novosad, 2016), and the strength of the off-farm sector (Khandker et al., 2009). Similarly, there is evidence of increased cash crop production, but also of poorer beneficiaries increasing their focus on staple crops (Sieber & Allen, 2016; Setboonsarng, 2008; Aggarwal, 2018). Improved infrastructure has also been found to facilitate value chain access, diversification and lucrative specialisation in some cases (Broegaard et al, 2011; Lakshmanan, 2011; Luo & Xu, 2018), but elsewhere evidence suggests these benefits are only available to those with high initial resource endowments, especially land (Qiaolun, 2006; Fujita, 2017).

Increased income from the pathways outlined above can enable the purchase of assets to increase productivity or manage risk, and can also encourage investments in improving social outcomes such as social capital, education, and better diets (Trivelli et al., 2017; Bucheli et al., 2018). Direct effects on these key social indicators of rural transformation can also occur through reduced transport time to schools and markets for healthy food. Social capital can also be directly enhanced as improved mobility and communication, and better-attended local marketplaces, facilitate collective action and group formation (Bradbury, 2006; IIED, 2017). This latter effect can have particular benefits for coping with climatic shocks through mutual support networks, for instance by borrowing money from a rotating fund (Chigwada, 2005).

The importance of contextual factors and resource endowments means that the impacts of infrastructure on the inclusivity of rural transformation are unpredictable and likely to be context specific (Starkey & Hine, 2014). Impacts on inclusivity are also noted as being heavily dependent on the type of infrastructure, or combination of infrastructures, to which households are exposed (van de Walle, 2009; Chowdhury, 2010; Hansen et al., 2011). Despite evidence of pro-poor impacts in some cases (Mu and van de Walle, 2007; Aggarwal, 2018), interventions have also been found to increase inequality where the poorest households are unable to take advantage of the potential benefits (Haider et al., 2018). A key risk is that households with low productive capacity are forced out of increasingly competitive markets (Winters, 2014; Asher & Novosad, 2016).

Improved infrastructure can offer new opportunities for income generation for women, one of the groups most at risk of exclusion, but could also increase the migration of males leaving female household members with a greater work burden (Chowdhury, 2010; Mohun & Biswas, 2016; Slavchevska et al., 2016). Impacts may also be hampered by cultural constraints faced by women which improved infrastructure may be insufficient to overcome (Asher and Novosad, 2016). There is some evidence that rural infrastructure can increase wage and self-employment opportunities for women in some settings (Lokshin & Yemsov, 2005; Aggarwal, 2018; Ahmed & Nahiduzzaman, 2016), but also that women and female-headed households can be excluded, or can benefit economically to the detriment of their overall work burden (Chowdhury, 2010; Rahman, 2014).

4.3 Context

Bangladesh is one of the most climate vulnerable countries in the world, facing increasingly severe seasonal flooding, cyclones and drought, especially in the southwest region (Christensen, 2012). Despite this, improvements in agricultural technology have contributed to relatively fast rural transformation in recent years, but imbalances in access to land, assets, markets, credit, education, and healthcare, has meant the process has not been inclusive (Gautam & Faruqee, 2016; IFAD, 2016). The lack of inclusivity applies especially to women, who face considerable economic and social constraints based on cultural norms (Ambler et al., 2017). In addition, with cropping intensity reaching its limit, furthering rural transformation requires different drivers such as on- and off-farm diversification, improved value-added and marketing, and more consolidated value chains (Rahman, 2014; Gautam & Faruqee, 2016). As outlined in the previous section, better rural connectivity through improved infrastructure has the potential to unlock these new avenues (Fujita, 2017).

CCRIP was implemented between 2013 and 2019 with a budget of $150 million, and covered 12 districts across the divisions of Barisal, Dhaka and Khulna in southwest Bangladesh. The project sought to improve livelihoods through improved connectivity by building and improving a range of rural infrastructure including large-scale rural roads and large "Growth Center" markets, smaller community and village roads and markets, bridges and culverts, and cyclone shelters. The focus of this case study is solely on the impact of the smaller community and village roads and markets (implemented using $40.5 million of the project budget).

The project's strengthening of community and village markets—selected for support based on their remoteness, poverty, and potential for impact—is intended to increase their year-round usability and their management. This involves constructing facilities such as sheds, river docks, internal roads, and toilets; installing raised and paved areas and improving drainage systems to increase resilience to flooding; and providing capacity building training to MMCs. CCRIP also improved the main road that connects each market to the surrounding communities in order to increase its year-round usability (especially during the monsoon season when roads are likely to be submerged and damaged), raising and paving the roads with material resistant to frequent submersion by salty or brackish water, and lining them with vetiver grass to prevent erosion.

The project also targeted women through the Public Works approach (see Slater & McCord, 2009). This involved training and hiring mainly destitute women through Labour Contracting Societies (LCS) to conduct some of the construction work for the project. This was expected to provide women with skills and experience that would improve their economic participation even after the project. In addition, as part of the MMC capacity building training, they encouraged that each MMC include a quota of female members.

Within each project area, households may benefit from being close to both the upgraded market and the improved market-connecting road, or may only benefit from being located close to the market and not the road. Both sets of households are expected to benefit from improved demand, prices, input access, local economic opportunities and social networks through better-attended markets that are operational year-round regardless of shocks. While those located close to the road could benefit more from undisrupted and cheaper transport to local and non-local markets as well as to schools and group meetings. If this is the case, they stand to ultimately benefit more in terms of increased income and livelihood transformation. Whether this is the case is an empirical question that we test in our analysis.

4.4 Data and methodology

4.4.1 Data and indicators

The empirical analysis is based on data from in-depth household questionnaires from 1,350 treatment and 1,650 control households, surveyed in August-September 2018 from the three divisions where CCRIP was implemented.[13] The questionnaire covered the three annual cropping seasons during the 12-month period between August 2017 and July 2018. Households were sampled from the surrounding areas of nine CCRIP markets (work on all of which was completed before June 2015) and nine control markets. CCRIP was implemented by first identifying suitable markets, and then improving the market and its main connecting road. Based on this, the sample was designed by first identifying well-matched treatment and control markets before randomly sampling households from within their catchment areas.

Key to the sample design was defining the catchment areas for the markets and roads of CCRIP according to their zones of influence (van de Walle, 2009). Local project specialists estimated

[13] A representative sample was obtained by weighting the sample size per division based on the relative project expenditures per division.

that the maximum distance that households would be willing to travel to utilise the markets is approximately 2km, while for the roads, the distance is 0.5km. In order to assess the impact of the market alone, as well as the incremental impact of the market and the market-connecting road, we stratified the sample according to two catchment areas: (i) within a 2km radius of the market but not within 0.5km either side of the market-connecting road; and (ii) within a 2km radius of the market, and within 0.5km on either side of the market-connecting road.

Treatment and control markets were identified using a combination of GIS data and input from project specialists. Control markets were identified from a list of markets that narrowly missed-out on being selected for the project due to financial constraints, in addition to other markets proposed by local staff in the project divisions as having been similar to CCRIP markets at the time of the project's initial implementation. The final set of treatment and control markets were then selected using GIS data by producing matched pairs of markets that were geographically close (ideally in the same upazila) but whose catchment areas were not overlapping (to avoid spillover), and who shared similar population densities.

In addition to the household questionnaires, extensive qualitative data was collected from senior national and regional project staff, and from other key figures in both treatment and control areas. In the treatment areas, this included: five KIIs with MMC members in CCRIP markets; five FGDs with LCS members involved in roads construction; and five FGDs with LCS members involved in market construction. In control areas, this included: three KIIs with control market managers; and two KIIs with the local Women's Representatives (in the absence of active LCS in these areas).

We use the quantitative data to construct a set of impact indicators designed to comprehensively assess the project's impact on inclusive rural transformation. In addition to indicators of agricultural production, livelihood composition, school enrolment, and social capital (proxied by membership of a local social group) we also construct an index for ownership of household and productive assets using Principle Component Analysis (see Filmer & Pritchett, 2001), along with Food Insecurity Experience Scale (FIES) and Household Dietary Diversity Scale (HDDS) scores.[14]

To assess impacts on resilience to shocks we use subjective measures of the severity of a shock's impact and the household's ability to recover from the shock. These are two key aspects of resilience, with severity assessing the degree of vulnerability of a household to a shock, and recovery assessing the household's ability to cope in its wake (OECD, 2014; FSIN, 2015; Schipper & Langston, 2015). Both of these are based upon a five-point scale. In order to assess the project's specific impact on resilience to climatic shocks, we construct these indicators separately for climatic shocks (floods, cyclones, storms, etc.) and non-climatic shocks (loss of employment, illness or death of a household member, etc.).

4.4.2 Methodology

Using the household data, we estimate the impact of CCRIP by catchment area, and within each catchment area we assess whether impacts were different for landowners, in order to assess the influence of initial resource endowments. As noted above, land ownership has proven to be a key influencing factor in past impact studies, and is a reliable indicator of pre-project resource endowments as it is mostly fixed over the short-term. We do not estimate impacts for non-landowners due to insufficient sample size, but we can infer how impacts differed for these households by comparing the impact estimates for the entire catchment area and for landowners within the area.

We use a statistical matching-based approach to estimate impacts on these sub-groups. Broadly, matching-based approaches are used to increase the comparability of treatment and

[14] The FIES is a score based on responses to eight questions related to experiences of food insecurity during the 12 month study period (Ballard et al., 2013). The HDDS is a score based on the consumption of 16 different food groups during the seven days preceding the day of the questionnaire (Kennedy et al., 2011).

control groups by only comparing households matched according to a set of relevant pre-project characteristics. After testing various matching approaches, we identified a non-parametric, mahalanobis distance-based radius matching model as our primary estimator. This estimator provided the highest level of bias reduction while minimising the number of households dropped from the analysis for not having a match. The mahalanobis distance is a matrix-based method of determining the distance between two units based on multiple data points (Hill & Lewicki, 2006). In this case we use this measure to find treatment and control households with the smallest distance according to a set of relevant characteristics,[15] and we match treatment households with all control households within a specified radius. The average difference in the impact indicator for each matched pair provides the Average Treatment Effect (ATE) of the project on that indicator (Abadie et al., 2004). Formally, the ATE from this model for a given impact indicator is calculated as follows:

$$\text{ATE} = E(y_{1i} - y_{0i}) \qquad (4.1)$$

Where y_{1i} represents the outcome for treatment household i, and y_{0i} represents the outcome for control household i, and the E is the expectation operator.

Our preferred estimator reduces the average SMD between the covariates from 0.09 to 0.03 and VR from 1.14 to 1.01 (Austin, 2009), indicating that the process considerably improves the comparability of the treatment and control group based on observable characteristics. We also assess the sensitivity of the results of this model using a secondary model and find that the results are qualitatively similar.[16]

[15] These consist of the household size and dependency ratio; average age in the household; age, education and gender of the household head; number of literate and English-speaking household members; Religion; number of climatic shocks experience in the past 12 months; Productive and household assets owned at baseline (2014); and the upazila in which the household is located.

[16] We use an IPWRA model, as used in Chapter 2, to test sensitivity of results to model specification. The specification and results of this model are available upon request from the contact author.

4.5 Profile of the sub-groups

Table 4.1 presents key economic and social statistics of households in the two catchment areas, including separate statistics for landowners and non-landowners. Treatment and control households located close to both the market and the road have a higher average income than treatment and control households located away from the road, and within both catchment areas landowners unsurprisingly have higher incomes. The amount of land cultivated is low in all cases, but especially for those located away from the road. Non-landowners in this area cultivated an average of just 0.8 hectares through renting, sharecropping or borrowing.

School enrolment is also similar across the sub-groups, with each averaging around 70-72 per cent, as is average years of households' education, although again in both cases the average for landowners within the groups is higher. Women's decision-making involvement is low in all cases, with only 35-45 per cent of treatment and control households reporting that women are involved either solely or jointly in decisions regarding household purchases, reflecting the country's well-documented equality issues (Ambler et al., 2017; Matin, 2017). Shock exposure during the 12-month study period is high across the groups, with similar proportions of households reporting being affected by floods (10-11 per cent), cyclones or storms (2-4 per cent), and other shocks such as illness or death of a family member of loss of employment (48-55 per cent).

Table 4.1. Key characteristics of sub-groups

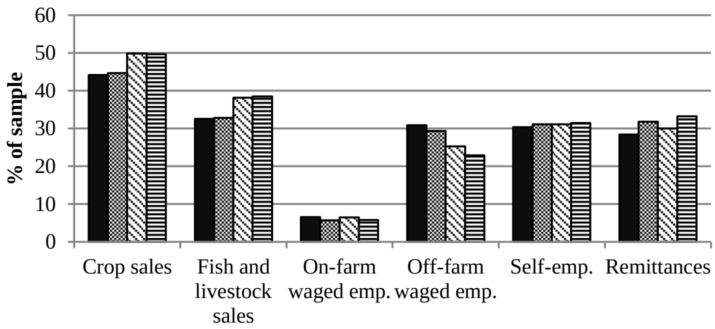
	Market only			Market & Road		
	All	**Land-owners**	**Non-landowners**	**All**	**Land-owners**	**Non-landowners**
Total income per capita ($)	2,246	2,402	1,643	2,532	2,707	1,749
Land cultivated (ha.)	2.8 (985)	3.3 (786)	0.8 (199)	3.2 (891)	3.5 (737)	1.6 (154)
Years of ed. in household	6.0	6.2	5.3	6.2	6.3	5.6
School enrolment (%)	69.9 (1,207)	70.1 (951)	69.5 (256)	71.4 (997)	72.0 (801)	68.9 (196)
Women involved in decision-making on household purchases (%)	35.3 (1,483)	36.5 (1,178)	30.5 (305)	42.6 (1,247)	44.7 (1,019)	33.3 (228)
Shock exposure (% of households):						
– Flood	10.9	10.4	12.7	10.3	10.2	10.5
– Cyclone/Storm	4.2	3.5	6.8	2.3	2.3	2.6
– Non-climatic	52.6	53.5	48.9	49.5	48.2	55.3

Number of households, unless otherwise stated in parentheses: Market only: All = 1,491, Landowners = 1,184, Non-landowners = 307; Market & Road: All = 1,249; Landowners = 1,021, Non-landowners = 228.

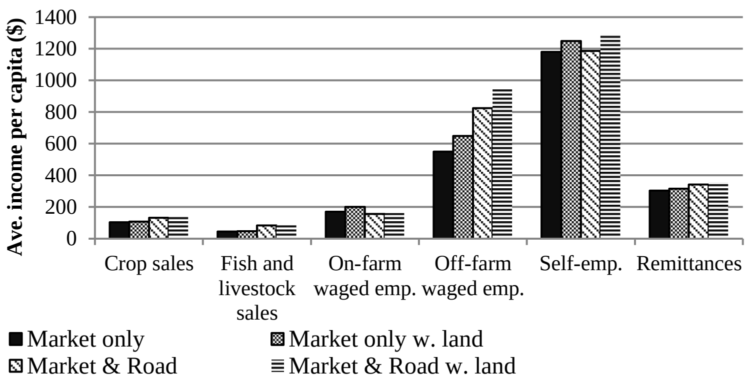
Graphs 4.1a and 4.1b provide an overview of the livelihood composition of the sub-groups. Graph 4.1a shows that selling crops is the main livelihood activity for all of the sub-groups, with little variation by land ownership, although no more than 50 per cent of households in each case are involved in this activity. Sales of fish and livestock are the second most popular livelihood activity across the groups. For both catchment areas, around 30 per cent of households are involved in self-employment, whilst those treatment and control households located away from the road have a higher level of involvement in off-farm wage employment (31 per cent) compared to those closer to the road (25 per cent). Amongst those treatment and control households located away from the market, landowners have a slightly lower level of involvement in wage employment and are more involved in self-employment. Remittances are also a key part of livelihoods in both catchment areas, especially for landowners, whilst participation in on-farm wage employment is low in all cases.

Graph 4.1b presents the average income per capita earned from each activity for each of the sub-groups. The average income from crop sales is much lower than self-employment and off-farm wage employment. Being located closer to the market-connecting road seems particularly beneficial for off-farm wage employment. Treatment and control landowners do not seem to benefit from larger incomes from selling crops in either catchment area, but they have higher incomes per capita in both areas from self-employment and off-farm wage employment. That landowning households obtain higher average incomes in almost all sectors highlights than non-landowners—with their higher poverty, lower resource endowments and lower education—are the most at risk of exclusion from any rural transformation processes occurring in the study area.

Graph 4.1a. Participation in livelihood activities



Graph 4.1b. Average income by activity



4.6 Results

4.6.1 Agricultural Productivity and Marketing

Table 4.2 presents results for CCRIP's impact on crop, fish and livestock production. We find that the project did not significantly increase crop productivity or fish production for households located in either catchment area, regardless of land ownership, and the value of livestock production was only significantly increased for households located away from the road (by 25 per cent). We also find a significant impact on this indicator when the sample is restricted solely to landowners in this catchment area, although the smaller coefficient implies that the impact may have been higher for non-landowners in this area.

In terms of income from agriculture (Table 4.3), the project had large significant impacts on income from selling crops for both catchment areas, with a larger impact for those located away from the road (150 per cent vs 81 per cent). As with the impact on livestock production, the effects on income from crop sales were lower in both catchment areas for landowners, suggesting a larger impact on non-landowners. Despite the lack of impact on fish production, income from selling fish increased for both catchment areas, which was due to higher prices and a higher proportion of fish harvests being sold according to both the quantitative and qualitative data. Finally income from livestock increased alongside production for those located away from the road, again with a smaller impact for landowners.

The results for crop productivity and sales broadly suggest that the project improved market access for selling outputs but not for buying inputs. Further analysis of the quantitative data supports this in terms of selling outputs, highlighting that positive impacts were driven by increases in the proportion of harvests being sold, the likelihood of selling crops at a market rather than from the farm gate, and the likelihood of growing cash crops. Regarding buying inputs, however, responses in the qualitative data indicate that affordability hindered input use despite improvements in physical access.

Further analysis of the quantitative data on the sale of seasonal crops reveals that the project increased income from the sale of seasonal crops in both the dry and monsoon seasons. Importantly, this indicates that all-weather access and usability of markets for farmers was improved. The role of MMCs in improving and maintaining market access in the face of shocks—thanks to improved financial capacity from CCRIP training and higher rents collected from better attended markets—was widely reported as a key factor in the qualitative data. Furthermore, the overall crop income findings highlight that poorer households (those located away from the road and non-landowners) benefitted more, and the higher impacts for those located away from the road also implies that the market strengthening activities were the main driver behind these agricultural impacts.

Table 4.2. Impact of CCRIP on crop, fish and livestock production

	Value of total crop prod./ha.	Value of total fish prod.	Value of total livestock prod.
Market only	17.1% (985)	-11.8% (865)	25.2%** (1,170)
Market only w. land	18.5% (786)	-11.3% (726)	23.4%** (936)
Market & Road	10.8% (891)	-31.9% (661)	-2.6% (1,001)
Market & Road w. land	8.14% (737)	-31.9% (545)	-0.8% (806)

Note: Sample size varies according to the number of households involved in the activity in each case, sample size indicated in parentheses;
*,** and *** indicate the statistical significance of the estimated ATE at the 10, 5 and 1% levels, respectively.

Table 4.3. Impact of CCRIP on crop, fish and livestock income

	Value of crop sales/ha.	Value of total fish sales	Value of total livestock sales
Market only	150.4%*** (985)	59.6%* (865)	69.3%** (1,170)
Market only w. land	100.2%***(786)	33.7% (726)	48.7% (936)
Market & Road	81.2%** (891)	70.6%** (661)	-32.9% (1,001)
Market & Road w. land	70.1% (737)	59.2% (545)	-52.4% (806)

Note: Sample size varies according to the number of households involved in the activity in each case, sample size indicated in parentheses;
*,** and *** indicate the statistical significance of the estimated ATE at the 10, 5 and 1% levels, respectively.

4.6.2 Total Income and Livelihood Activities

Table 4.4 presents the results for CCRIP's impact on total income, livelihood diversity, and income from wage and self-employment, and remittances. Total income was only significantly increased for those located away from the road (13 per cent), and the lack of impact for landowners within this catchment area suggests that this impact was driven by improvements for non-landowners. For those located close to the road we do not find a significant impact despite the increase in agricultural income noted above.

Along with income from agriculture, the increase in total income for those located away from the road was driven by income from employment, especially off-farm work. Further analysis indicates that this impact is based on an increase in wages rather than in labour days, implying that the project helped these households to identify more lucrative employment opportunities rather than increasing overall wage employment. Further quantitative and qualitative investigation into non-landowners in this catchment area reveals that similar employment impacts were not achieved, potentially due to their lower education and skills, and that income impacts were instead driven solely by agricultural income.

Despite the importance of self-employment in the livelihoods of households in all of the sub-groups (see Graph 4.1a), we do not find an impact on income from this source for any group. There was also no mention in the qualitative data of the project benefitting self-employment or migration, suggesting that this type of local market and road infrastructure may not be conducive to these activities. However, we do find that income from remittances was increased for those located close to the connecting road, suggesting the road provided opportunities for more lucrative migration, seemingly more so for non-landowning households.

Regarding income diversification, this was increased significantly for those located away from the road, with the impact likely to be higher for non-landowners. For non-landowners located away from the road, the poorest group in the sample, further analysis shows that this impact was driven by increased involvement in agricultural sales. Along with the lack of impact on off-farm income for this sub-group, we also do not find an impact on the number of households involved in off-farm employment for either landowners or non-landowners located away from the road. In the case of non-landowners, these impacts indicate that resilience through diversification seems to have been developed within existing agrarian livelihoods for these households. Conversely, for households located close to the road, their diversification did not increase but testing for impacts on the number of households involved in off-farm wage employment shows that that involvement did increase, especially for landowners. This has positive implications for climate resilience, alongside the increase in income from remittances, given that these activities are commonly at a lower risk of disruption from climatic stressors, and can provide a buffer against harvest failure (Svodziwa, 2018).

Table 4.4. Impact of CCRIP on total income and income sources

	Total income per capita	Nr. income sources	Income per capita from: On-farm employment	Off-farm employment	Self-employment	Remittances
Market only	12.7%*	0.3**	34.2% (98)	17.8%* (460)	-26.6% (457)	-9.0% (424)
Market only w. land	3.5%	0.2	40.1% (68)	18.5% (347)	-33.0% (372)	-16.6% (377)
Market & Road	7.5%	0.04	-82.9%*** (81)	8.6% (316)	5.7% (390)	32.2%* (375)
Market & Road w. land	7.2%	0.1	-78.5% (59)	9.3% (234)	2.2% (322)	28.9% (339)

Note: Full sample used for all indicators, unless otherwise stated in parentheses, with the following sample sizes: Market only = 1,491; Market only w. land = 1,184; Market & Road = 1,249; Market & Road w. land = 1,021;
*,** and *** indicate the statistical significance of the estimated ATE at the 10, 5 and 1% levels, respectively.

4.6.3 Asset Ownership, Social Outcomes and Shock Resilience

Table 4.5 presents the results for CCRIP's impact on asset ownership and social outcomes. The project did not increase asset ownership for any of the sub-groups. Involvement in social or community groups, an indicator of social capital, was increased only for households located close to the road, suggesting that the market-connecting road was the key factor in this impact pathway. Qualitative responses also indicate that households were able to travel to meeting points more easily year-round using the upgraded roads.

Food insecurity was found to have significantly decreased only for those located close to the road, by an average of 0.4 on the eight-point scale. Without improved agricultural production, higher incomes may have driven this impact. Dietary diversity was not improved, however, and we actually find a significant reduction for landowners located away from the road. This could be linked to the increased market orientation of agriculture, meaning that a smaller variety of crops were produced for home consumption. Table 4.1 also shows that males are the main decision-makers regarding household purchases, which has also been found to lead to less household income being spent on nutrition (Amugsi et al., 2016). School enrolment was also not increased for any of the sub-groups. In the qualitative data, households reported improved access to schools in some cases, meaning the lack of impact may be partially due to school enrolment already being reasonably high (see Table 4.1).

Table 4.5. Impact of CCRIP on asset ownership and social indicators

	Asset index (0-12 score)	Nr. social/ community groups involved	FIES (0-8 score)	HDDS (0-16 score)	School enrolment (%)
Market only	0.04	0.04	-0.4***	-0.2	-1.0 (1,207)
Market only w. land	0.01	0.02	-0.5***	-0.3*	-1.4 (951)
Market & Road	-0.01	0.08***	-0.2	-0.01	-0.2 (997)
Market & Road w. land	-0.01	0.06**	-0.2	-0.1	-0.9 (801)

Note: Full sample used for all indicators, unless otherwise stated in parentheses, with the following sample sizes: Market only = 1,491; Market only w. land = 1,184; Market & Road = 1,249; Market & Road w. land = 1,021;
*,** and *** indicate the statistical significance of the estimated ATE at the 10, 5 and 1% levels, respectively.

Table 4.6 presents the results for CCRIP's impact on household's subjective resilience to shocks. In terms of climatic shocks, we find significant improvements for both catchment areas, with slightly higher impacts for land owning households in both cases. According to these results, the average reported score on the scale for shock severity (five being the most severe) was reduced by an average of 0.3 points for both catchment areas, whilst the average reported score on the scale for households' ability to recover from the shock (five being a full recovery), was increased by an average of 0.4 for those located away from the road and 0.6 for those located close to the road. By enhancing improved seasonal market access, and livelihood diversification and off-farm activities for some sub-groups, the project has had a clear impact on climate resilience in the project areas. The project's impact on social capital may have also contributed to households' ability to recover by enhancing coping mechanisms through improved support networks (Adger et al., 2001).

The results are less promising for other shocks, the prevalence of which remains high in the sample (see Table 4.1). We do not find significant reductions in non-climatic shock severity or ability to recover for either catchment area, regardless of land ownership. This may be linked to the lack of impact on asset ownership (a key coping resource), and perhaps because remote rural households require more extended periods of income growth, asset accumulation, and livelihood transformation to reduce their overall vulnerability (Tanner et al., 2017). This prevailing vulnerability may also help to explain the lack of impact on agricultural productivity and advancement into more lucrative off-farm activities amongst some households, as high risk exposure is known to disincentivise productive investments for the sake of low-risk, low-return investments (Rosenzweig & Binswanger, 1993; Yesuf & Bluffstone, 2009; Hurley, 2010).

Table 4.6. Impact of CCRIP on shock resilience

	Severity of climatic shocks (1-5 score†)	Recovery from climatic shocks (1-5 score††)	Severity of other shocks (1-5 score)	Recovery from other shocks (1-5 score)
Market only	-0.4*** (220)	0.4** (220)	0.1 (784)	0.1 (784)
Market only w. land	-0.5*** (160)	0.4** (160)	0.1 (634)	0.1 (634)
Market & Road	-0.3** (149)	0.6*** (149)	-0.1 (618)	0.1 (618)
Market & Road w. land	-0.4*** (121)	0.5*** (121)	-0.03 (492)	0.03 (492)

† Scale: 1= Low severity, 5 = High severity; †† Scale: 1= Did not recover at all; 5 = Full recovery
Note: Sample size varies according to the number of households who experienced at least one shock during the 12 month period in each case, sample size indicated in parentheses;
*,** and *** indicate the statistical significance of the estimated ATE at the 10, 5 and 1% levels, respectively.

4.6.4 Women's Inclusion and Empowerment

As shown in Table 4.7, the contribution to household income by women's autonomous economic activities was not improved amongst any of the sub-groups, and the likelihood of women owning their own business was also not increased, which may be symptomatic of the overall lack of impact on self-employment activities. At the same time, women's likelihood of having off-farm wage employment was improved for both catchment areas, while there were too few women in on-farm employment in any group to analyse this impact.

The project specifically aimed to improve the economic inclusion of women through the use of LCS. Respondents in the qualitative data noted that this initiative provided useful training and a temporary income increase, but once the construction work was completed, members struggled to find further employment, and when they did, they were paid lower wages compared to men. Such discrimination in wages may explain the lack of impact on household income contribution despite increases in off-farm wage employment, but may also reflect them being in a lower standard of employment.

Regarding social capital, women were actively involved in an average of 0.03 more groups for those located away from the road and 0.05 more groups for those located close to the road (both of which are statistically significant)—again highlighting the importance of roads to social capital impacts. Within these groups, the findings suggest that the impact was higher for non-landowners in the former, and was not different in the latter. For women in households located away from the market, there was also a significant increase of six per cent in the likelihood of their being involved in decisions about household purchases, although there was no impact for any group regarding decisions about children's schooling.

We have found that CCRIP stimulated rural transformation progress by advancing agricultural activities for some households, and off-farm activities for others, but these findings suggest women faced barriers to participating in these advancements. Qualitative data from project staff confirms that limits on women's mobility and labour were considerable barriers in this area, especially among Muslim households. In fact, further analysis shows that amongst the small number of non-Muslim households, women's contribution to household income did significantly increase. More positively, the improvements in social capital and decision making may represent the beginning of a longer term process of transformational economic and social change for women if these effects can be maintained.

Table 4.7. Impact of CCRIP on women's inclusion and empowerment

	Share of income in household total (%)	Own business (% likelihood)	In off-farm employment (% likelihood)	Nr groups	Involved in decision-making about (% likelihood): Household spending	Children's schooling
Market only	0.4	0.2	2.4**	0.03*	6.04**	0.2
Market only w. land	0.2	-0.4	2.1**	0.02	2.9	0.5
Market & Road	1.0	0.5	1.3	0.05***	-3.9	-1.6
Market & Road w. land	1.1	0.9	0.8	0.05**	-5.0	-1.0

Note: Only households with adult female members included, sample sizes are as follows: Market only = 1,483; Market only w. land = 1,178; Market & Road = 1,247; Market & Road w. land = 1,019.
*,** and *** indicate the statistical significance of the estimated ATE at the 10, 5 and 1% levels, respectively.

4.7 Conclusions

Using the case study of CCRIP in southwest Bangladesh, this paper investigates how upgraded rural markets and market-connecting roads can support inclusive rural transformation, applying a framework of impact indicators that incorporates changes in livelihood climate resilience.

Our findings provide strong evidence that investing in climate resilient market infrastructure in areas of high climate vulnerability can reduce household's vulnerability to climatic shocks and increase their ability to recover from them. It can particularly increase resilience to climatic stressors for agricultural marketing, leading to higher agricultural profitability regardless of initial resource endowments. Through sub-group analysis we also find that these impacts do not necessarily require additional connecting roads and can be achieved through upgraded markets alone. Qualitative insights highlight how strengthening local committees to manage the markets can contribute to the sustainability of these impacts.

However, the potential for this type of investment to stimulate other areas of inclusive rural transformation is far less clear. For poorer households, we find that they can benefit more than others in terms of agricultural income, total income, and income diversification, which has positive implications for inclusivity, but for the poorest (non-landowners located away from the road in this case), we find limited evidence that they are able to advance into the off-farm sphere, potentially due to limited education and skills. Whilst representing progress, in areas with limited space for increased cropping intensity such improvements may not be sustainable. Impacts were also mixed for relatively wealthier households. Whilst benefitting in terms of more profitable crop and fish production, more off-farm wage employment, and higher remittances, their livelihoods were not substantially strengthened due to a lack of impact on self-employment or income from wage employment, their main income sources.

We also find that increased income does not automatically unlock improvements in all of the components of rural transformation, especially in terms of asset ownership or social outcomes. For instance, we find that a lack of road access may hinder improvements in social capital, and increased market orientation of agricultural production may hinder improvements in dietary diversity. Without such improvements, we find that vulnerability to non-climatic shocks may persist, which in-turn may limit project impacts by maintaining risk aversion, potentially explaining the static nature of crop production practices for both groups, and the lack of advancement into off-farm activities for non-landowners.

Regarding women, we find widespread improvements in women's social capital as a result of the project, highlighting the power of improved rural connectivity to affect this important aspect of women's empowerment. On the other hand, we find limited evidence of women having improved their income generating activities or household decision-making involvement. Based on these findings, and as noted in previous studies, this type of project may be insufficient to structurally transform the position of women in the face of cultural barriers.

These findings provide many implications for future policy and practice. First, they confirm that increasing the usability of rural markets alone can increase livelihood resilience to climatic stressors in climate vulnerable areas, and adding market-connecting roads can generate further improvements, especially in terms of increasing social capital. Future initiatives can magnify these impacts by ensuring households can afford to purchase inputs from these markets, helping to generate greater productivity and resilience impacts. Also in terms of resilience to both climatic and non-climatic shocks, future initiatives would also benefit from facilitating the transfer of increased incomes into increased asset accumulation, and capitalising on the strong linkages between rural infrastructure and social capital.

For poorer households, impacts on resilience and income can be furthered by facilitating the investment of increased agricultural income into a more lucrative mix of on- and off-farm activities. Based on the barriers identified in this study, this can be achieved through skills training and provision of capital to increase agricultural productivity and to invest in off-farm ventures. For wealthier households, they must be targeted with more nuanced support that is focused on making non-farming activities more lucrative. This can be achieved by ensuring that a wider range of goods are traded at the local markets or by improving connectivity to larger markets.

Finally, future initiatives in countries such as Bangladesh must place greater emphasis on overcoming the barriers to economic and social inclusion faced by women. If not, women are at risk of being excluded from rural transformation progress and having their unequal position in society further entrenched. This analysis has shown that improving connectivity through markets and roads can have powerful effects on women's social capital. Future initiatives should try to build upon this mechanism, using collective action and networks to generate new opportunities for breaking social norms, increasing skill acquisition, and increasing opportunities for wage and self-employment. Based on the findings regarding the use of LCS, this may serve as an effective tool in this regard if future applications place greater emphasis on generating longer term benefits.

Chapter 5

Protecting farm productivity from the effects of seasonal floods in Bangladesh

A Stochastic Meta-Frontier analysis of a climate resilient infrastructure project

Abstract: This chapter assesses the impacts of CCRIP on farm productivity. The analysis combines Stochastic Meta-Frontier modelling and counterfactual-based impact evaluation methods to test whether the project improved agricultural productivity, and whether impacts varied by flood exposure. The findings indicate that average Frontier Output grew only for beneficiaries with low flood exposure. TE increased for beneficiaries with high flood exposure, but only for those who had been exposed to recurrent floods over time, which we attribute to a change in coping strategies. Our results also indicate that it was harder to improve access to agricultural inputs than for selling outputs. Based on the analysis, we suggest complementary support that could help to increase the impacts of future rural infrastructure projects.

This chapter is based on:

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5.1 Introduction

Ensuring that extreme weather events do not temporarily or permanently hinder access to markets for inputs and outputs is key for achieving sustainable improvements in productivity for smallholder farmers in developing countries. Unreliable market access hampers productivity as farmers cannot acquire the inputs they need at the required time and may be reluctant to invest in new technologies and practices because of uncertainty about reaping adequate returns (OECD, 2007; Taylor et al., 2009; Zezza et al,. 2011; FAO, 2018b). This has implications for short-term productivity and food security, and for the longer-term transformation of rural economies that is key for wider economic growth (IFAD, 2016).

This chapter provides much-needed evidence on how to address development challenges stemming from climatic shocks in rural areas, focusing on the effectiveness of flood-proof rural markets and market-connecting roads implemented through CCRIP in southwest Bangladesh. We take a sample of treatment and control households, which we trim using Coarsened Exact Matching (CEM) to increase comparability, and then apply a SPF analysis to estimate the project's impacts on several agricultural productivity indicators.

The marginal benefit of climate-proofing new infrastructure is unclear as most existing studies do not attempt to clarify their impact pathways (Douven et al., 2012). For instance, a new road designed to be climate resilient may fail in this aim but still improve livelihoods simply by being better than the previous road when the area is not flooded. To inform future project design, we try to uncover specific impact pathways by testing whether project impacts differ by flood exposure intensity (both short-term and recurrent).

The proceeding section reviews the relevant literature, followed by an overview of the case study project and its context, the data and methodology, descriptive statistics of the sample, the results of the analysis, and finally the conclusions and policy implications.

5.2 Related literature

Similar to Chapter 3, the approach used in this paper draws from two different strands of literature: (i) studies focusing on robust impact evaluations of climate resilient infrastructure projects; and (ii) studies investigating agricultural productivity differentials using SMFs. Studies from the former stream rarely go further than using output per hectare to measure impacts on agricultural productivity, whereas studies from the latter rarely address possible selection bias associated with entry into a given comparison group (Greene, 2010; Bravo-Ureta et al., 2012; Bravo-Ureta et al., 2020a). Moreover, both types of studies seldom examine the impact of markets and roads that are climate resilient. In combining the two streams, this chapter builds upon their respective strengths while addressing their shortcomings.

5.2.1 Assessing the impacts of climate resilient infrastructure projects

Access to infrastructure (such as roads, markets, irrigation and electricity) is recognised as one of the five main factors that determine the adaptive capacity of a community (Smit and Pilifosova, 2001), and there is a large body of evidence showing that investing in rural infrastructure is among the strongest ways to secure agricultural productivity against the threats of climate change (Binswanger, 1989; Binswanger et al., 1993; Nelson et al., 2010; ILO, 2011; Below et al., 2012). Enabling farmers to navigate the effects of climate change—including increasingly frequent and severe climatic shocks—has now been mainstreamed into rural development policymaking (Frelih-Larsen, 2014; IFAD, 2019b), and based on its perceived effectiveness, and lower maintenance and repair costs, increasing investment is being channelled into climate resilient infrastructure, defined as infrastructure that can “withstand, respond to, and recover rapidly” from changing climate conditions (OECD, 2018: 4).

Robustly estimating the impacts of development interventions, such as rural infrastructure projects, requires that beneficiaries are compared with a counterfactual that accurately represents how beneficiaries would have fared in the absence of the intervention (Winters et al., 2010). Although many impact evaluations of improved rural infrastructure have been conducted using this approach, climate resilient infrastructure investments have received limited attention (Douven et al., 2012; Sabet and Brown, 2018).

Existing evaluations of the impact of climate resilient infrastructure on agriculture focus predominantly on all-weather roads (Hine, 2016; Raitzer et al., 2019). For instance, a national all-weather road building programme in Ethiopia was found to have reduced the likelihood of being poor and increased household consumption, attributed partially to improved market access and increased purchasing of crop inputs (Dercon and Hoddinott, 2005; Dercon et al., 2009). For a similar national programme in India, studies by Shamdasani (2016) and Aggarwal (2018) find that access to all-weather roads increased use of fertiliser, hybrid seeds, farm labour and irrigation, and supported a shift from subsistence to market-oriented agriculture. Shamsadani (2016) adds, however, that impacts were lower for small-scale cultivators who could not afford to increase farm investments.

Effective modelling of climatic shocks and stressors, and analysing the response of beneficiaries to these, is key to determining the impacts of climate resilient infrastructure. Smith and Frankenberger (2018) applied this type of test to a disaster mitigation project in northern Bangladesh to analyse the project’s effects on beneficiaries’ response to flooding. They define flood exposure using an index based on satellite data on stream flows combined with self-reported severity. They find that the project helped to reduce the negative effects of flood exposure on food security which they attribute partially to flood effects being mitigated by improved access to input markets and to financial services. Asfaw et al. (2017) assess the impact of a conditional cash transfer project on the effects of drought in Zambia, defining exposure based on negative deviation of rainfall from the district-level mean. The findings indicate that the project ensured that household expenditures and nutrition were not negatively affected by drought, especially for the poorest households.

Analysing the influence of drought on household expenditures in Ghana, Tanzania and Uganda, Haile et al. (2018) report that effects differ temporally and according to the number of shocks experienced, highlighting the need to focus on both short-term and recurrent shocks. While a one-off shock may not be significant enough to cause long-term damage to the livelihood of a household, recurrent shocks can gradually degrade livelihood capacity, by eroding resources, savings and social capital, and by promoting long-term risk averse decision-making behaviour (Rosenzweig and Binswanger, 1993; Blaikie et al., 1994; World Bank, 2013; Birhanu et al., 2017).

Investigating the ability to cope with recurrent shocks can also help to uncover the coping strategies that are employed before and after a shock. So-called negative coping strategies, such as the sale of assets, could help households to overcome a temporary shock but are likely to reduce their ability to cope with future shocks, meaning that the harmful effects of these strategies would only become evident when subsequent shocks occur (Smit and Skinner, 2002; Smit and Wandel, 2006; Nguyen et al., 2020). By mitigating the negative effects of shocks, climate resilient infrastructure has the potential to reduce the need to resort to these detrimental coping strategies, which include ex-ante risk averse strategies such as avoiding investing in new technologies or higher value crops that are costlier to produce (Liebenehm et al., 2018). Focusing on individual coping strategies is particularly important in the case of floods, which usually affect whole communities meaning households are unable to rely on social networks to cope (Kurosaki, 2015; Nguyen et al., 2020).

Béné and Haque (2021) provide a rare analysis of the impact of a development project on coping strategies, assessing the ability of a multi-faceted development project to build the resilience of fishery users, in the same area of coastal Bangladesh as our case study project.

They categorise coping strategies such as selling productive assets or taking a loan in response to a shock as detrimental, and strategies such as income diversification or saving money as adaptive or transformative. While the results of the project's impacts on negative coping strategies are inconclusive (although there is an indication that impacts vary by shock), they find a strong positive impact on promoting adaptive/transformative coping strategies. They conclude that it may be easier to promote positive strategies than to induce the rural poor to avoid negative strategies. A similar assessment is applied by Béné et al. (2020) to a disaster risk reduction project in Niger, focusing on responses to drought, flood or other shocks. Complementing findings on indicators of shock recovery and food security, they find similar results in that the project only reduced the probability of engaging in detrimental coping strategies for five out of 25 of the shock-response combinations that they tested, and increased the probability of engaging in positive responses in six out of ten cases.

5.2.2 Assessing agricultural productivity differentials using SMFs

More efficient farm production means that less natural and physical inputs are required per unit of output, meaning that production is less affected if access to these inputs is hindered due to a climatic shock (McCarthy et al., 2011). For example, more efficient production means farmers can produce more on a smaller amount of land, which would allow them to cope with growing land degradation (IPCC, 2019). Higher agricultural productivity can also lead to higher incomes, which can then be invested in new inputs, machinery and practices that further increase farmers' ability to withstand shocks and to navigate worsening threats from climate change (Lipper et al., 2014). In terms of mitigation, more efficient agriculture usually incurs a lower unit cost in terms of emissions, and lessens the demand for forests and wetlands to be converted for farming (Lipper et al., 2014; Searchinger et al., 2018). Rural development policies are beginning to recognise these benefits, but methodologically robust evidence on the impacts of infrastructure projects that aim to increase the efficiency of agricultural production are scarce (World Bank, 2011; Cameron et al., 2016).

Agricultural productivity can be increased in various ways, including improved input and technology access, and more efficient input use. The majority of existing impact evaluations of projects aiming to improve agricultural productivity use total output as the main indicator of productivity—but without knowing how total output was affected, the causal pathways remain unknown (Headey et al., 2005). Employing a production frontier approach provides a more granular analysis of productivity, allowing to first identify a producer's maximum potential output from a given set of inputs, technology and environment, and then to assess TE based on the distance between the maximum potential and the corresponding observed output (Aigner et al., 1977; Battese and Coelli, 1992). Production frontier methodologies have considerable, largely untapped, potential to enhance the analysis of how development interventions affect agricultural productivity (Bravo-Ureta et al., 2012; Bravo-Ureta et al., 2020a).

To assess the impact of an intervention on Frontier Output and TE, treated and control groups must be compared against a common benchmark frontier. TE scores are not comparable if production is dependent on group-specific frontiers that do not share the same technology. The MF approach, introduced by Battese et al. (2004) and refined by O'Donnell et al. (2008), provides a common benchmark to make valid productivity comparisons across groups that exhibit different technologies. The method consists of using linear programming to derive a frontier that envelopes the individual group frontiers under the assumption that all producers have access to the same production technologies, but that individual groups can use different technologies depending on their resources and farming conditions. Using this best-practice approach, Villano et al. (2015) find that adopters of certified rice seeds in the Philippines had a significantly higher MTE (i.e. TE with respect to the Meta-Frontier) of 62 per cent compared to non-adopters who averaged only 37 per cent. Adopters also enjoyed a significantly higher annual predicted Frontier Output (6,242 kg/ha) compared to non-adopters (5,114 kg/ha).

More recently, Huang et al. (2014) developed the SMF approach that we apply in this chapter, which has received very limited attention in the literature. One such application is by Alem et al. (2018) who compare the efficiency of dairy farms in Norway across five regions with different climatic and production conditions. They find minimal differences across regions, with MTE scores averaging between 87 per cent and 89 per cent. The SMF approach has also been used by Lawin and Tamini (2019) to compare the TE of landowners and non-landowners amongst smallholder farmers in Benin. They find that non-landowners are significantly more efficient with an average MTE score of 82 per cent, compared to 45 per cent for landowners, which they suggest may be due to better farm managers choosing to enter the land rental market.

To date, the similar analysis conducted for Chapter 3, based on the paper by Bravo-Ureta et al., 2020b, is the only study known to the authors that has used the SMF approach to assess the impact of a development intervention. As explained in Chapter 3, we find that treated farmers expanded their production frontiers compared to control farmers but did not improve TE due to a lack of support to enhance farm management, reporting that MTE scores for beneficiaries averaged 59 per cent against 70 per cent for controls.

Although comparing TE using a common benchmark frontier allows for a meaningful comparison across different groups who may access different technologies, if assignment to groups is not random then the comparison may be biased. Recognising this risk, some studies have employed causal inference methods commonly used in impact evaluations to address potential selection biases. In addition to the analysis in Chapter 3, the aforementioned studies in Benin (Lawin and Tamini, 2019), and the Philippines (Villano et al. 2015) do so using propensity score-based techniques to mitigate bias from observable covariates between the comparison groups. This involves estimating propensity scores for treated and control units, using a logit or probit model, to determine the likelihood of being in the treated group based on a set of relevant covariates. Then, treated and control units are matched based on the proximity of their propensity scores and those units without a match are dropped. An alternative is to assign a weight to each unit based on their scores (Caliendo and Kopeinig, 2008). Recognising possible bias from unobservable characteristics—which is a potential shortcoming when PSM approaches are used alone—the SC-SPF framework that addresses bias from unobservables, as employed in Chapter 3, is an attractive methodology for impact evaluation (see Greene, 2010; Bravo-Ureta et al., 2012; De los Santos-Montero and Bravo-Ureta, 2017).

5.3 Context and research questions

As explained in Chapter 4, CCRIP aimed to increase resilience to flooding in one of the most flood-prone countries in the world, focusing on the southwest region where, especially in the low-lying char lands, vulnerability is especially high (Huq et al., 2015; Maplecroft, 2018). In addition to occasional extreme weather shocks, such as cyclones and storm surges, large areas are submerged by flooding during the monsoon season months (June-September) each year, and this problem is growing in intensity due to climate change (Brouwer et al., 2007; Hossain et al., 2012). The area is populated by remote poor households whose main livelihood activity is small-scale agriculture, and for whom heavy seasonal floods pose considerable threats to their crop production and sales.

The project was expected to improve agricultural productivity through three main channels. First, improved access to local markets, which is not interrupted during the monsoon season, is expected to allow farmers to buy the right inputs at the right time, and potentially of higher quality and at lower prices, and to access more and better information. This equates to improved access to technology, which is expected to expand their production possibility frontier (Bravo-Ureta and Pinheiro, 1993). Second, secured access to well-attended local markets for sales should provide higher returns for harvests, which is expected to incentivise farmers to invest in more effective and efficient farm management, thus increasing their TE (Taylor et al., 2009). Third, a less direct impact is expected through the project's potential effect on off-farm income. Studies have confirmed that off-farm income can help to increase investment and smooth cash flow cycles in agriculture in the face of extreme weather (Ruben and van den Berg, 2001; Abebe, 2014; Ahmed and Melesse, 2018). However, there is also evidence that increased off-farm income has led to agriculture being deprioritised, thus exerting a negative or neutral effect on farm productivity (Alene and Hassan, 2003; Obwona, 2006; Bäckman et al., 2011).

As such impacts do not necessarily require that the infrastructure is climate resilient, so to determine the additional benefits, we assess the importance of the CCRIP infrastructure being flood-proof by testing whether impacts vary according to flood exposure. Although flooding is ubiquitous during the monsoon season in the study area, the test takes advantage of the variation in exposure. Our hypothesis is that higher impacts for less exposed households would mean that CCRIP mainly achieved its impacts by generally improving market access, rather than ensuring that the infrastructure is fully functional for all purposes linked to production during times of intense flooding. Treated and control households are categorised into sub-groups in two ways: (i) Short-term exposure - determined by flood exposure during the 2017-2018 study period; and (ii) Recurrent exposure - measured according to exposure to recurrent floods between 2014, when the project began, and 2018, when the survey was implemented. By comparing different treated and control sub-groups using the two alternative exposure definitions, we can determine whether CCRIP's flood-proofing strengthened productivity against both temporary shocks in the short-term and recurrent shocks over the longer term. The questions that are addressed through different sub-group comparisons are summarised in Table 5.1.

Table 5.1. Summary of sub-groups and research questions

Sub-group comparison	Research question
Treated with high short-term exposure vs control with high short-term exposure	Did CCRIP help beneficiaries to maintain or improve their productivity during and immediately following an extreme flood event?
Treated with high recurrent exposure vs control with high recurrent exposure	Did CCRIP help beneficiaries to maintain or improve their productivity in the face of recurrent floods over multiple production cycles?
Treated with low short-term exposure vs control with low short-term exposure; Treated with low recurrent exposure vs control with low recurrent exposure	To what extent did the impacts of CCRIP accrue for households with low flood exposure?

5.4 Data and methodology

The analysis is based on cross-sectional data from a household questionnaire, and geo-coded rainfall data. We combined the same household dataset used in Chapter 4, covering a sample of 1,873 small-scale farm households (803 treated and 1,070 control)[17], with rainfall data sourced from the Climate Hazards Group Infrared Precipitation and Station (Funk et al. 2015). Based on the resolution of the rainfall data, a total of 28 data points spread across the sample were generated. Thus, each rainfall data point covered an average of 59 households.

The empirical methodology involves four steps: (i) statistical matching to increase the comparability of the treated and control groups; (ii) calculating indicators of flood exposure using the rainfall data; (iii) estimating separate SPFs for each sub-group along with a benchmark SMF; and (iv) analysing differences in estimated Meta-Frontier Output, TGRs and MTE between treated and controls for the various sub-groups using t-tests.

[17] The household questionnaire covers the three annual cropping seasons between 2017-18, beginning with the Kharif II (July 2017-November 2017), Rabi (November 2017-March 2018) and the Kharif I season (March 2018-July 2018).

The intention of the first step is to create a set of treated and control households who would have had a similar chance of being a beneficiary of the project when it was first implemented. Although reasonably balanced treated and control groups were obtained through the sampling strategy, matching at the household level is used to address any remaining differences. This matching is done using a CEM approach, which involves assigning each household to a stratum based on a set of relevant matching variables, with continuous variables "coarsened" into categories to facilitate the stratification (Iacus et al., 2012; Sidney et al., 2015). A treatment household was then dropped from the sample if it was assigned to a stratum that did not contain at least one control household, and vice versa for control households. This broader strata-based CEM approach is preferred over PSM for two reasons: (i) assigning households to strata requires less parameters to be set a priori (such as the number of nearest neighbours or the matching radius) compared to pair-wise matching, leaving it less open to researcher bias (Iacus et al., 2012); and (ii) CEM has a lower risk that households in the middle of the distribution (i.e. those who are similar to the average household in the sample and who should be kept) are dropped for not having a match (Sidney et al., 2015).

Based on seven categorical matching variables, a total of 217 strata were created, of which 106 contained at least one treated and one control household.[18] The remaining 111 strata contained 117 treated and 99 control households who were dropped from the sample, giving a final sample size of 1,657 households, 686 treated and 971 control. Appendix 5.A contains the average SMD for each of the matching variables for the raw and trimmed samples. The average SMD across the variables before trimming of 0.15 was reduced to 0.06, which is well below the 0.1 threshold that is commonly considered as an acceptable maximum value (Austin, 2009).

[18] The matching variables are: gender and education of the household head; the household's religion and dependency ratio; amount of land owned with a title; an index of the assets owned by the household in 2014 (based on recall data); and geographical location (division) of the household.

These figures suggest that the samples are well balanced and that the risk of bias in the final analysis based on observable variables is minimal.

The second step of the methodology is to create the flood exposure variables to be used for splitting the sample. Informed by the methods employed in past studies (see Dercon 2004; Thiede, 2014; Asfaw et al. 2017), we first calculated how much each household's rainfall deviated from the sample average for their district in each monsoon month during the 12-month questionnaire reference period.[19] We then took the sum of the monthly deviations in rainfall and assigned households to a high or low short-term exposure category if the sum of their monthly rainfall deviation was above or below the median deviation for the sample, respectively. We then applied the same process for each preceding year dating back to 2014 (the first year of the project), assigning households to a high or low exposure category in the same way for each of these years. Based on this we grouped households by recurrent flood exposure according to the number of years they were above the median rainfall deviation. If a household was above the median rainfall deviation for more than one year, then it was assigned to the high recurrent exposure category.

Table 5.2 presents the distribution of households according to the two definitions. There are **275** households assigned to the high short-term exposure/low recurrent exposure group, and *192* households assigned to the low short-term exposure/high recurrent exposure group. This means that around 28 per cent of the sample have a different short-term and recurrent exposure status, while the rest either have both high short-term and recurrent exposure (621 households, 38 per cent) or low short-term and recurrent exposure (569 households, 34 per cent). It is important to remember when interpreting the results that the groupings are not mutually exclusive. For instance, households with high short-term exposure are not being compared with

[19] These months covered August and September 2017, and June and July 2018. District-level rainfall statistics are from the Bangladesh Meteorological Department (2014).

a separate set of households with high recurrent exposure, rather the question is first whether short-term exposure during the study period influenced the project's impacts, and then whether the results change when households are allocated by recurrent exposure.

Table 5.2. Number of households assigned to each flood exposure group

	High recurrent exposure	Low recurrent exposure
High short-term exposure	621	**275**
Low short-term exposure	*192*	569

The third and fourth steps involve estimating productivity indicators, and then comparing these indicators between the treatment and control groups using t-tests to measure the project's impacts.

The need for an SMF is determined by comparing the parameters of a pooled SPF model with those of group-specific SPFs. If there is no significant difference in the parameters, then a simple pooled SPF that includes binary variables for the groups would be appropriate, as this suggests that all households in the sample employ the same technology set (except for the intercept). This is determined using a likelihood ratio test as outlined by Battese et al. (2004). Separately for the short-term and recurrent exposure groupings, we test the null hypothesis that parameters estimated by the group-specific frontiers are not different from the pooled frontier. Rejecting the null hypothesis indicates that the groups do utilise different technology sets and should be compared using a benchmark SMF.[20]

The two-step stochastic regression method of Huang et al. (2014) is used to estimate the Meta-Frontiers. The first step involves the estimation of the group-specific Cobb-Douglas production frontiers as follows:

[20] The loglikelihood (LL) function for the pooled SPF is -1771.93, and the sum of the LL functions for the short-term exposure groupings is -1714.15, and for the recurrent exposure groupings is -1704.12. In both cases, this gives a Likelihood Ratio statistic that is above the critical value from the Chi-square Distribution, based on 39 degrees of freedom.

$$\ln Y_{gi} = \ln f^g(X_{gi}) + V_{gi} - U_{gi} \qquad (5.1)$$

where Y_{gi} is output—measured as the observed value of production based on median prices for each crop—for household *i* in group g, X_{gi} is a vector of inputs applied by household *i* in group g, f^g is the group-specific production frontier, V_{gi} is the standard 2-sided normally distributed error, and U_{gi} is the one-sided error denoting the inefficiency of household i in relation to its production frontier. The one-sided error term is assumed to follow a half-normal distribution. The evidence indicates that results are robust with respect to different distributional assumptions, and that the half-normal is favoured because of its relative simplicity (Kumbhakar and Lovell 2000; Coelli et al. 2005).[21] The Cobb-Douglas and transcendental logarithm (or translog) have been the two most commonly used functional forms for this type of analysis (Bravo-Ureta et al., 2007; Ogundari, 2014). While TE results from these two forms have been found to be very similar in different contexts (e.g., Baccouche and Kouki, 2003; Bravo-Ureta et al., 2020c) we opt for the Cobb-Douglas because it satisfies regularity conditions imposed by microeconomic theory globally and this is not the case for the translog (Ahmad and Bravo-Ureta, 1996; O'Donnell, 2012; O'Donnell, 2016). The choice of inputs was based on the literature, contextual knowledge and data availability.

The benchmark SMF is then estimated using the predicted group-specific frontier values as the dependent variable as follows:

$$\ln\hat{f}^g(\mathrm{X}_{gi}) = \ln f^m(\mathrm{X}_{gi}) + \mathrm{V}_{gi}^m - \mathrm{U}_{gi}^m \qquad (5.2)$$

where f^m is the SMF that envelopes the group specific frontiers, and U_{gi}^m denotes the gap between the frontier of group g and the Meta-Frontier.

[21] As the selection of households was random in the market areas and the intervention was not specifically targeted within a given areas, there is no need to employ the selectivity-corrected SPF model of Greene (2010), something confirmed by a log-likelihood test for bias from unobservables.

The TGR is equal to a household's estimated group-specific production frontier estimated from Equation 5.1 ($\ln\hat{f}^{g}(X_{gi})$) divided by their meta-production frontier estimated from Equation 5.2 ($\ln\hat{f}^{m}(X_{gi})$). Once the TGR is calculated, a household's MTE is obtained by multiplying the TGR by the corresponding group-specific TE (e^{-Ugi} from Equation 5.1). Thus, the MTE takes into account the distance between each group's individual frontier and the overall Meta-Frontier, as well as the output shortfall for each individual relative to its own frontier. These two steps are outlined below in equations 5.3 and 5.4:

$$\widehat{TGR}_i^g = \frac{\ln\hat{f}^g(X_{gi})}{\ln\hat{f}^m(X_{gi})} \qquad (5.3)$$

$$\widehat{MTE}_i = \widehat{TGR}_i \times \widehat{TE}_{gi} \qquad (5.4)$$

This process of estimating group-specific SPFs and a benchmark SMF is done twice, once with the sample divided by exposure to short-term flood exposure, and again with the sample divided by recurrent exposure. There are four groups in each case—treated households with high exposure, control households with high exposure, treated households with low exposure, control households with low exposure. Hence, four production frontiers and one SMF are estimated for the short-term exposure grouping, and the same for the recurrent exposure grouping. The analysis thus generates two different estimates of a household's Meta-Frontier Output, TGR, TE and MTE according to the two exposure groupings. These values for the groups are then compared using t-tests.

It is important to define what each of these components represent in our analysis. The TGR reflects an outward or technological shift of a group-specific frontier, placing it closer to the Meta-Frontier and thus increasing maximum potential output (Meta-Frontier Output). Based on this definition, these indicators are likely to be affected by changes in access to technology and information. TE is an indication of managerial performance with respect a group's own frontier, while MTE is a summary measure that combines both the technology and the managerial (TE) effects.

5.5 Profile of the sub-groups

Table 5.3 presents livelihood characteristics of the different sub-groups, separated by flood exposure as explained above. Across the groups, the statistics are reflective of small-scale farm households. They cultivate around three hectares of land with slim margins between the value of production and inputs, and the majority of their harvest is consumed rather than sold. In this area, rice is the predominant crop, followed by mung bean, betel nut and coconut. Details of the cash income of the sample highlights that off-farm activities are an important complement to agricultural production, with between 60-70 per cent of household cash income coming from off-farm activities. Households with greater exposure to flooding produce lower harvest values per hectare, and use less inputs. Recurrent exposure would understandably be expected to cause more damage to livelihoods, and those with low exposure produce more per hectare, and have higher land and input use, and cash income.

Table 5.3. Livelihood characteristics of sample households by flood exposure

	Short-term		Recurrent	
	High exposure	**Low exposure**	**High exposure**	**Low exposure**
Value of harvest ($/ha.)	521.91	571.98	522.56	566.44
Land cultivated (ha.)	3.3	2.4	2.6	3.2
Value of inputs ($/ha.)	360.13	462.43	391.19	422.45
Main crops grown				
- Rice	75.5	79.5	73.7	80.81
- Mung bean	34.4	25.4	28.0	32.35
- Betel nut	24.4	11.0	22.0	14.69
- Coconut	19.8	13.1	17.5	16.00
- Khesari	10.5	12.8	11.8	11.26
- Mango	15.6	7.4	13.0	10.66
Proportion of harvest sold (%)	29.9	33.5	29.8	33.2
Proportion of sales made at a market (%)	17.3	15.0	12.3	20.1
Total cash income ($)	936.17	679.67	807.47	828.87
Observations (treated/control)	**896 (280/616)**	**761 (406/355)**	**813 (279/534)**	**844 (407/437)**

5.6 Results

5.6.1 SPF and SMF parameters by flood exposure

Tables 5.4a and 5.4b present the parameter estimates for each explanatory variable included in the short-term and recurrent exposure groupings, respectively (see Appendix 5.B for the mean values of the explanatory variables used in the models). The results in Tables 5.4a and 5.4b are the basis for the productivity analysis that follows. The parameters in both tables for land, labour, inputs and paid labour are positive and significant as expected, while expenditure on machinery is only significant for some of the sub-groups. Being located inland, away from the char areas, has a strong positive effect on output across the sub-groups for both the short-term and recurrent exposure groupings. For both of the flood exposure groupings, differences in the parameters of land ownership and crop diversity, among others, highlight the need for a benchmark SMF. In addition, differences in the parameters for the same sub-groups (for example, treatment with high exposure) when grouped by short-term or recurrent flood exposure highlight the value of using two flood exposure definitions.

The parameters for the proportion of land that is owned, crop diversity, and off-farm income are all negative, although only significant in some cases, while in most instances the age and education of the household head, and having received agricultural extension support, does not seem to be influential. [22] The results for off-farm income suggest that, in this context, the potential positive effect on farm production of greater and more stable cash income is outweighed, potentially by a lower priority given to agriculture.

Table 5.4a. Parameters of SPFs and SMF by short-term flood exposure

	High - Treated	High - Control	Low - Treated	Low - Control	SMF
Constant	9.610***	9.797***	9.942***	9.419***	9.963***
Area (log)	0.355***	0.406***	0.440***	0.386***	0.413***
Labour days (log)	0.208***	0.161***	0.198***	0.139***	0.193***
Expenditure on fertiliser, pesticide and seeds (log)	0.032*	0.076***	0.046***	0.054***	0.049***
Expenditure on machinery (log)	0.031*	0.021	0.037**	0.036**	0.030***
Labour that was paid (%)	0.746***	0.479***	0.681***	0.447***	0.635***
Proportion of cultivated land that is owned (%)	-0.225**	-0.046	-0.179**	-0.266***	-0.149***
Herfindahl-Hirschman crop diversity index	-0.465***	-0.233***	-0.143	-0.439***	-0.222***
Proportion of off-farm income in total income (%)	-0.821***	-0.716***	-0.612***	-0.302***	-0.650***
Head above age 40 (yes/no)	0.180*	0.017	-0.072	-0.001	0.019**
Head more than four years of education (yes/no)	0.012	-0.012	0.044	0.140**	0.045***
Received agricultural extension support (yes/no)	0.108	0.165**	0.022	0.169*	0.099***
Inland (yes/no)	0.129	0.389***	0.355***	0.309***	0.374***
Observations	280	616	406	355	1,657

Note: *, ** and *** indicate statistical significance at the 10, 5 and 1% levels, respectively.

[22] The Herfindahl-Hirschman index has been inverted in this case for ease of interpretation, meaning that a higher score represents greater diversification.

Table 5.4b. Parameters of SPFs and SMF by recurrent flood exposure

	High - Treated	High - Control	Low - Treated	Low - Control	SMF
Constant	9.022***	9.512***	9.959***	9.745***	10.018***
Area (log)	0.384***	0.449***	0.450***	0.355***	0.416***
Labour days (log)	0.106***	0.144***	0.236***	0.148***	0.217***
Expenditure on fertiliser, pesticide and seeds (log)	0.087***	0.076***	0.039***	0.061***	0.039***
Expenditure on machinery (log)	0.031	0.039***	0.029*	0.013	0.029***
Labour that was paid (%)	0.405***	0.481***	0.751***	0.480***	0.694***
Proportion of cultivated land that is owned (%)	-0.151	-0.125**	-0.168*	-0.118	-0.155**
Herfindahl-Hirschman crop diversity index	-0.538***	-0.200***	-0.112	-0.454***	-0.182***
Proportion of off-farm income in total income (%)	-0.562***	-0.414***	-0.654***	-0.635***	-0.654***
Head above age 40 (yes/no)	0.064	0.062	0.006	-0.074	0.005
Head more than four years of education (yes/no)	0.051	0.067	0.017	0.002	0.056***
Received agricultural extension support (yes/no)	0.178	0.080	0.011	0.209**	0.101***
Inland (yes/no)	0.161	0.358***	0.243***	0.347***	0.334***
Observations	279	534	407	437	1,657

Note: *, ** and *** indicate statistical significance at the 10, 5 and 1% levels, respectively.

5.6.2 Comparison of productivity indicators

Tables 5.5a and 5.5b present the t-test results for the indicators of productivity derived from the models. Treated households with low short-term flood exposure have a significantly higher Meta-Frontier Output compared to the control group (averaging $1,169 vs $833), and a significantly higher MTE (52 per cent vs 49 per cent), driven by an improvement in the TGR. For the high short-term exposure grouping, there is no significant difference in Meta-Frontier Output or MTE between the treated and control groups, stemming from a lack of improvement in the TGR which mitigated the positive and significant effect on TE. For the recurrent flood exposure grouping, treated households with low exposure have a higher MTE (47 per cent vs 43 per cent), driven by a reduction in their TGR, but the difference in Meta-Frontier Output is not significant for treated households with low or high short-term exposure. Unlike treated households with high short-term exposure, treated households with high recurrent exposure have a significantly higher MTE compared to the control group (51 per cent vs 47 per cent).

When households are grouped by short-term flood exposure, Meta-Frontier Output and MTE were only improved by CCRIP in areas with low exposure, indicating that impacts were hindered by extreme flooding. When households are grouped by recurrent flood exposure, however, we find that the project was able to improve MTE for those with high exposure. That the high recurrent exposure group has the lowest average income in the sample (see Table 5.3) implies a pro-poor impact of the project, echoing findings of the aforementioned study of a conditional cash transfer project for climate vulnerable households in Zambia (Asfaw et al., 2017).

The project aimed to improve access to inputs (including seeds, fertiliser, pesticides, machinery and information), and thus Meta-Frontier Output, by establishing well-attended markets that functioned year-round. A potential explanation for the lack of impact on input access for the high exposure groupings is that suppliers of higher quality inputs may have needed to travel from farther away to access these markets, having to use other roads before reaching the local market-connecting road installed by the project, meaning that they could not reach some of the markets more heavily affected by flooding. While positive impacts on input access were found for an all-weather road project in India, this may be because roads were implemented on a larger scale compared to CCRIP (Shamdasani, 2016).

The project mainly aimed to improve farm management, and thus MTE, by increasing the potential returns from crop sales and thus incentivising and facilitating more efficient practices. The results indicate that these objectives were achieved in areas with low short-term or recurrent flood exposure. The project was also expected to indirectly improve MTE by loosening liquidity constraints through enhanced off-farm income generation, but based on the negative parameters for off-farm income in all models exhibited in Table 5.4a and 5.4b, this potential impact pathway is not supported in this context.

The positive impact on MTE for households exposed to recurrent flooding sheds further light on the project's impact pathways. The implication is that, before the project, treated and control households subjected to recurrent shocks did not have incentives to optimise their farming practices, or had implemented long-term risk averse coping strategies. Then, with improved access to markets, the potential for larger and more reliable benefits from market participation increased treated households' incentives to improve their farm management (i.e. TE) compared to their control counterparts. Following this reasoning, and informed by discussions with project staff, the difference in the impacts on Meta-Frontier Output and MTE for this group may be because, whilst suppliers of better inputs may have had to travel farther to reach project markets, buyers of produce may have been closer, meaning they could still have accessed project markets by the connecting road during floods.

The different MTE impacts by short-term and recurrent flood exposure also has implications for the project's impacts on coping strategies. The lack of impact for the high short-term exposure grouping may have been due to control households maintaining their farming practices in-line with treated households through unsustainable coping strategies, such as drawing down assets. However, when households are grouped by recurrent exposure, the impact on MTE of the treated farmers under high exposure is positive. This implies that treated households with high recurrent exposure benefitted by avoiding detrimental coping strategies thanks to sustained market access, causing impacts to gradually arise compared to control households with similar exposure.

For further investigation, Graphs 1a and 1b plot the estimated MTE scores for the treated and control households according to the number of months during which they experienced high flood exposure between 2014 and 2018 (based on being above the median rainfall deviation for the sample for each month). The respective trend lines show that the MTE of treated households increases with the number of recurrent floods they faced, and that of control households decreases. For control households, the implication is that, without market access that can be maintained during flooding, a farmer seemingly has less incentive to produce close to their frontier, perhaps instead deciding to invest more in off-farm activities (shown in Tables 5.4a and 5.4b to be negatively associated with farm output).

The findings suggest that for treated households, production frontiers likely contracted in-line with recurrent flooding, as highlighted in Table 5.5b by the higher average Meta-Frontier Output for treated households with low recurrent exposure compared to those with high exposure ($1,398 vs $787). Based on this, MTE might have risen gradually with recurrent exposure as management performance improved, remained steady, or simply decreased at a lower rate compared to Frontier Output, leading to more floods being associated with a higher MTE. This gradual improvement echoes the findings of the previous study by Béné et al. (2020) of a disaster mitigation project in Niger. Their study concludes that adopting positive and avoiding detrimental coping strategies as a result of the project often produced benefits in the mid- to long-term, meaning project impacts were not always immediately apparent.

Table 5.5a. T-tests of productivity indicators by short-term flood exposure

	Meta-Frontier Output	**TGR**	**TE**	**MTE**	**Obs**
High flood exposure					
Treated mean	$1,084	73.8%	68.9%	50.8%	280
Control mean	$1,097	85.3%	58.9%	50.2%	616
P-Score	0.885	0.000***	0000***	0.471	
Low flood exposure					
Treated mean	$1,169	91.5%	56.5%	51.7%	406
Control mean	$833	73.6%	66.9%	49.1%	355
P-Score	0.000***	0.000***	0.000***	0.002***	

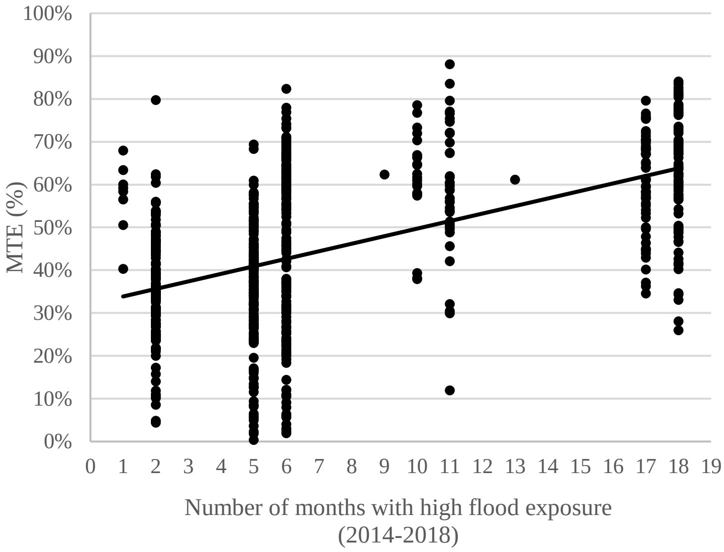
Note: *,** and *** indicate statistical significance at the 10, 5 and 1% levels, respectively.

Table 5.5b. T-tests of productivity indicators by recurrent flood exposure

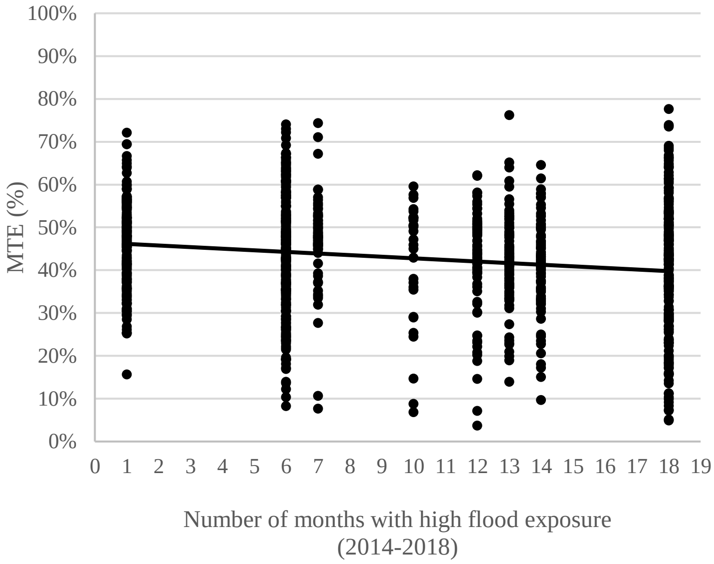
	Meta-Frontier Output	TGR	TE	MTE	Obs
High flood exposure					
Treated mean	$787	51.4	98.8%	50.8%	279
Control mean	$895	79.6	58.8%	46.8%	534
P-Score	0.139	0.000***	0.000***	0.000***	
Low flood exposure					
Treated mean	$1,398	89.3	52.4%	46.8%	407
Control mean	$1,344	69.7	61.9%	43.2%	437
P-Score	0.613	0.000***	0.000***	0.000***	

Note: *,** and *** indicate significance at the 10, 5 and 1% levels, respectively.

Graph 5.1a. Mean MTE by recurrent flood exposure: Treated households



Graph 5.1b. Mean MTE by recurrent flood exposure: Control households



5.7 Conclusions

Our results provide evidence that constructing flood-proof local markets and market-connecting roads can have positive impacts on farm productivity, but that impacts differ according to flood exposure and by productivity indicators.

The key finding of this paper is that, for beneficiaries with a high level of recurrent flood exposure, the project helped them to better manage their farms in the face of these recurrent shocks. The results imply that the project helped these beneficiaries to avoid detrimental coping strategies compared to control group households with the same level of exposure, and incentivised farm management efforts with the prospect of more reliable returns. This incentive may have led farmers to undertake higher risk/reward production and farm investment options stemming from better trading conditions and information coming from improved market access. Data constraints preclude us from investigating further the changes in coping strategies, but the findings highlight this as a potentially fruitful area for future research. The lack of impact on Meta-Frontier Output—a reflection of input access rather than production incentives—for the high recurrent exposure grouping suggests input supply chains are more vulnerable and harder to protect from recurrent shocks compared to those for outputs.

The positive effects of CCRIP on coping strategies and incentives highlight the role that climate resilient infrastructure can play in promoting broader rural transformation in climate-affected areas. That the sub-group with the lowest average income benefitted the most also highlights the potential for climate resilient infrastructure projects to improve the inclusivity of rural transformation processes and to reduce inequality and poverty.

Our finding that better access to inputs and information benefitted only those with low short-term flood exposure confirms the potential for generally improved rural markets and market-connecting roads to expand production possibilities. However, the lack of impact for other groups implies that further support and planning is required to ensure that benefits can be sustained even under higher and repeated exposure conditions, which would subsequently help to improve the cost-effectiveness of climate-proofing the infrastructure. We also find that the well-documented positive effect that off-farm income can have on farm productivity by easing liquidity constraints did not occur, thus highlighting another area where complementary support could help to augment impacts.

Based on these findings, an effective form of complementary support for future rural infrastructure projects in similar contexts would be to take additional measures to support input access and liquidity. To do so, future projects could map the location of input providers and implement strategies to ensure that they are able to access the local markets (or that producers can access them) even under extreme weather exposure. Support could also be combined with forecast-based cash transfers provided before flooding occurs, especially to those in high or repeated exposure areas, an intervention that has proven successful in Bangladesh and could ease potential liquidity constraints related to accessing key inputs (Gros et al., 2019). A study by Afrin et al. (2017) in Bangladesh finds a positive link between financial inclusion and TE, and given the well-documented challenges to financial inclusion among smallholders in the country (see Anderson et al., 2016), efforts to improve access to credit, formal or mobile phone-based bank accounts, and savings services could also be an effective means of facilitating investments in improved inputs and other efficiency-enhancing measures.

In terms of methodological insights, the difference in the findings between Frontier Output and TE, and between flood exposure categorisations, highlights the value of using more granular measures of productivity and shock exposure when assessing the impacts of rural development projects.

Appendix 5.A: SMD of raw and trimmed samples

	Raw sample			Trimmed sample		
	Treatment mean	Control mean	SMD	Treatment mean	Control mean	SMD
Land owned (ha.)	0.30	0.25	-0.12	0.25	0.23	-0.05
Female household head (%)	6.80	10.70	0.14	6.30	5.60	-0.03
Household is muslim	83.62	93.55	0.32	94.13	95.56	0.06
Dependency ratio	60.51	66.79	0.12	59.87	65.48	0.11
Ed. of household head (yrs)	4.27	3.92	-0.09	4.17	3.83	-0.09
Baseline asset index score	1.22	1.15	-0.08	1.13	1.15	0.01
Average SD (magnitude)	-	-	0.15	-	-	0.06

Appendix 5.B: Average values of Production Frontier variables

Table 5.B.1. Average values by short-Term flood exposure

SPF Variable	**High flood exposure**		**Low flood exposure**	
	Treatment	**Control**	**Treatment**	**Control**
Total value of harvest	867.65	675.67	780.23	403.15
Land cultivated (ha.)	3.66	3.12	2.99	1.81
Labour days	35.32	33.72	41.73	30.82
Expenditure on fertiliser, pesticide and seeds	48.51	55.40	56.05	56.42
Expenditure on machinery	48.35	44.91	52.75	41.18
Labour that was paid (%)	32.33	26.62	33.27	29.66
Proportion of cultivated land that is owned (%)	64.23	60.55	64.57	61.18
Crop diversity index (hhi)	0.61	0.56	0.60	0.50
Proportion of off-farm income in total income (%)	66.88	70.79	62.50	68.62
Head above age 40 (yes/no)	75.00	71.75	78.82	80.56
Head more than four years of education (yes/no)	38.21	43.34	52.22	43.10
Received ag. extension (y/n)	13.21	7.79	11.33	14.08
Located inland (y/n)	28.93	43.99	35.47	23.38
Observations	280	616	406	355

Table 5.B.2. Average values by recurrent flood exposure

SPF Variable	High flood exposure		Low flood exposure	
	Treatment	**Control**	**Treatment**	**Control**
Total value of harvest	694.29	452.63	899.29	726.83
Land cultivated (ha.)	3.67	1.98	2.99	3.44
Labour days	25.39	33.00	48.52	32.24
Expenditure on fertiliser, pesticide and seeds	54.90	62.83	51.66	47.14
Expenditure on machinery	38.95	46.93	59.18	39.40
Labour that was paid (%)	29.47	26.55	35.23	29.18
Proportion of cultivated land that is owned (%)	61.47	58.33	66.46	63.77
Crop diversity index (hhi)	0.54	0.54	0.65	0.53
Proportion of off-farm income in total income (%)	73.07	74.54	58.26	64.46
Head above age 40 (%)	77.78	72.28	76.90	78.26
Head more than four years of education (%)	40.14	36.14	50.86	51.95
Received ag. extension (%)	11.11	8.05	12.78	12.59
Located inland (%)	13.62	29.96	45.95	44.39
Observations	279	534	407	437

Chapter 6

Conclusions

6.1 Summary of findings

This thesis responds to the lack of evidence on the links between improved rural infrastructure and the various components of inclusive rural transformation. Better understanding of these links can help to inform better policies and projects that make a larger contribution towards meeting the SDGs by 2030. By solving challenges including unreliable access to water, other inputs, and buyers that make farmers more risk-averse and with a lower incentive to invest in their livelihoods, improved irrigation, roads and markets are expected to accelerate inclusive rural transformation through various channels. This includes by enhancing agricultural productivity and hence food security and nutrition; providing incentives and opportunities for shifting into lucrative off-farm activities; promoting investment in assets and education thanks to higher incomes; increasing resilience to climatic and non-climatic shocks; providing the conditions to grow social capital; and facilitating equal social and economic inclusion of women. Broadly, we find varying levels of support for these links, and confirm that, while improved rural infrastructure is an important tool in promoting inclusive rural transformation, it should be combined with other complementary support (particularly institution building) in order to achieve balanced and sustainable impacts.

Our overarching research question asks how improved rural infrastructure impacts inclusive rural transformation, and how impacts are influenced by contextual factors. Below we collate the findings from the four chapters for each component of inclusive rural transformation in-turn, before discussing the implications for the transformation process as a whole.

6.1.1 Agricultural productivity and farm income

We find that impacts on agricultural productivity differ both by the type of infrastructure and the type of indicator. The irrigation project had a positive impact on rice yields, but in the absence of complementary support, had limited impacts on TE of farming, while the climate resilient market and road project had limited impacts on either crop or fish yields, but improvements in TE were more commonplace.

This difference in the impacts on yields and on efficiency are reflected in the findings for farm income. Without efficiency gains, we find varied impacts of the irrigation project on income from crop sales, and where positive impacts are observed, this is driven by more investment and volume, rather than increased profitability. However, we find broad-based positive impacts on income from selling both crops and fish for the market and road project. This higher profitability was seemingly driven by more efficient farming, combined with higher prices and more market-oriented production (including focusing more on cash crops), due to the incentive of better-attended markets that can be relied upon to function year-round. On the latter point, we find that market income was improved both in the dry and monsoon season, thus confirming the benefits of climate resilient infrastructure support. Conversely, the irrigation project, focusing mainly on the production of one staple crop, offered limited support to increase the vibrancy of local markets, and beneficiaries were often found to be locked into unfavourable cash-for-harvest arrangements with local traders that offered their best option to obtain inputs during the production phase. These arrangements also hindered the project’s efforts to foster collective marketing among beneficiaries.

Another key finding of this thesis is the powerful impacts that all of these types of rural infrastructure support can have on livestock production and income. Where there was an existing market for livestock products, irrigation was found to have a large impact on livestock production, potentially due to the irrigation also being used for grazing land and other livestock needs, or potentially due to more reliable crop production providing an incentive for households to increase their investment in this livelihood source. Similarly, we find that proximity to markets had a positive impact on livestock production.

We identify several contextual factors that influenced impacts on farm production and income. First we find that, while irrigation can have positive impacts on poorer households located downstream on the irrigation canals, their income from crop sales remained constrained by limited access to markets and inputs (which hindered their profitability). In fact, issues with accessing farm inputs of the required type and quality was an important influence on impacts for both case study projects. As mentioned, limited capital for inputs led some beneficiaries of the irrigation project to enter into unfavourable marketing arrangements, while for beneficiaries of the market and road project, some markets, while well-attended and functional, may not have sold all the required inputs for farm production (potentially as input sellers could not reach these remote local markets), thus influencing farmer's ability to increase yields.

With regard to the climate resilient market and road project, our results indicate that proximity to the improved markets was the main determining factor for the impacts on income from selling crops, fish and livestock. However, the group located close to the market and further from the connecting road were also poorer on average, meaning this finding may also reflect the pro-poor impacts of the project, which is also reflected in the higher impacts on farm income for functionally landless households.

Finally, in Chapter 5 we find that exposure to climatic shocks had an important influence on the impact of the market and road project on crop production. Specifically, we find the highest impacts on TE for the sub-sample of households with high exposure to recurrent climatic shocks over the past five years. This we attribute to the project changing incentives of households who have adapted their practices to these recurrent shocks. With the prospect of year-round functioning markets, they were seemingly induced to loosen their long-term risk averse coping strategies.

6.1.2 Income and livelihood composition

We find that impacts of rural infrastructure on total household income vary, and are not always closely linked with impacts on income from farming. We find that irrigation can have the largest impact on total income when it induces beneficiaries to enhance their livestock production and off-farm activities, specifically engagement in off-farm waged employment. Where irrigation induces beneficiaries to increase their focus on crop production, especially for a staple crop, this can lead to them foregoing other opportunities, which may not pay-off unless farming efficiency increases. Similarly in the case of the climate resilient market and road project, it was only where incomes were diversified, and again where off-farm employment increased, did we see a positive impact on total income for the full sample.

Across the infrastructure types, we find limited evidence of the projects catalysing significant shifts in livelihood composition that are characteristic of the rural transformation process. The main change observed both in terms of irrigation, and markets and roads, is enhancements in livestock production and off-farm waged labour. Conversely, we see limited evidence that at this stage the support has encouraged beneficiaries to move into lucrative forms of self-employment, to invest in new on-farm technologies such as post-harvest processing machinery, or to generally engage in a more diverse range of livelihood activities.

Many contextual factors seem to influence impacts on livelihood composition. We find that irrigation can have a positive effect on enhancing incomes from livestock production and off-farm waged employment only if existing market linkages are in place. In a project region where connectivity to local markets was limited, we did not see these effects. Attempting to solve this market proximity issue, the main insight from the market and road project is that the largest impacts on livelihood compositions was for those located close to the market but further from the connecting road, although as mentioned above this may reflect the project's pro-poor impacts. The results indicate a slightly higher impact for landed households on off-farm employment, which could be due to limited education and skills of the functionally landless. Where proximity to the connecting road was shown to be important, however, was in increasing remittances, an impact that was higher for functionally landless beneficiaries.

6.1.3 Asset ownership and resilience

We find that there is not a guaranteed link between higher incomes and asset accumulation, which has important implications for the long-term resilience of beneficiaries to climatic and non-climatic shocks. We find that higher incomes achieved through improved irrigation led to beneficiaries purchasing more productive assets. However, income gains through the market and road project were not converted to more assets. This we suggest is due to the latter group being poorer, and thus more likely to use their higher incomes for immediate needs rather than investing in household or productive assets.

Our results confirm that building climate resilient markets and market-connecting roads can ensure year-round market access in areas of extreme flooding, and can subsequently increase beneficiaries' ability to absorb and recover their livelihoods from climatic shocks. As discussed above, we also find that building this infrastructure can especially help to increase the resilience of farm production to recurrent climatic shocks. However, we note the risk that beneficiaries may have remained vulnerable to non-climatic shocks due to the lack of impact on asset accumulation. While we find a positive impact of irrigation on asset accumulation where incomes were increased, we also note a risk that the case study project, with its focus predominantly on rice production, may have increased vulnerability to crop-specific shocks by inducing a narrowing on livelihoods around rice production for some households.

In terms of factors that we find to have influenced impacts in this area, it is clear that promoting asset accumulation through rural infrastructure is more difficult for poorer households as investing in assets for them is not a priority. From the irrigation case study we also infer that existing market linkages are key to avoiding a narrowing of livelihoods and thus an increase in vulnerability to crop-specific shocks, as discussed in the previous section.

6.1.4 Food security and nutrition

Food security and nutrition were mainly expected to have been increased thanks to better crop production and higher incomes, as well as potentially due to better access to markets. While rice yields were improved, our findings for the irrigation project show that impacts on nutrition are more closely linked to changes in income. Where incomes were not increased, we find that dietary diversity did not increase, potentially due to the project mainly focusing on enhancing rice production. For neither of the case study projects do we find any evidence of a link between market access and food security or nutrition. We do, however, find a link between enhanced livestock income through improved irrigation and dietary diversity, which we find contributed to increased consumption of meat and eggs. There is also an unexpected implication in the Bangladesh case study that among some households increased market-orientation of farm production may have hindered dietary diversity as the majority of crops were produced for sale rather than home consumption, but this was not substantiated by the qualitative data.

6.1.5 Social capital

We do not find a direct link between improved irrigation infrastructure and involvement in community groups (which is our main indicator of social capital). However, results indicate that this infrastructure can contribute by increasing incomes, thus giving more capacity and time to engage in these groups. We also find that strengthening IAs to manage the systems can provide a channel for increasing beneficiaries' involvement in community activities, especially for women. For the market and road project, we find that proximity to the road had a strong impact on group involvement, while being close to the market alone did not. This finding suggests that providing an all-weather road to travel to meet others was the most important impact mechanism, as opposed to having a well-attended market to meet others, or being involved in a strengthened MMC, which did not have the same effect on social capital as the IAs in the irrigation project. While proximity to roads was the main influencing factor for the market and road project, for the irrigation project initial poverty levels seems to have a key determinant, with impacts on this indicator being higher for poorer households located downstream on the canals, which we attribute to greater involvement in IAs.

6.1.6 Education

This aspect of the rural transformation process was mainly expected to be improved through higher incomes, as well as potentially through improved access from climate resilient rural roads. This has proven the hardest indicator to investigate, and the main insight is perhaps that more focused studies are required to assess impacts on education. We find that where improved irrigation improved incomes, there is potential for increased educational enrolment. We also find that all-weather roads may make it easier for children to attend school, but further insights are limited given that school attendance was already high in the project area. One potential channel through which infrastructure projects could theoretically improve educational outcomes is by increasing efficiency of farm production, which would reduce the demand for children to stay at home and assist on the family farm, but we find limited indication of this mechanism in the quantitative or qualitative insights. Based on our findings, we do not uncover any contextual factors that may have influenced impacts in this area.

6.1.7 Women's empowerment

This is the key indicator that we use to determine the inclusiveness of the transformational impacts achieved through the two case study projects. Regarding women's economic inclusion, this seems less influenced by the type of infrastructure, and more by contextual factors. In terms of irrigation, in the areas where the support helped to spur transformational improvements in livelihoods, women were also found to increase their economic inclusion. While we find limited evidence of climate resilient markets and roads opening most channels for women's economic inclusion, we do find an increase in off-farm wage employment (although with potential wage discrimination). Our qualitative analysis suggests that in Bangladesh the limited impacts were due to restrictive social norms, especially for Muslim households.

We find stronger positive impacts in terms of women's social capital. We find that encouraging women's involvement in IAs is a powerful tool for increasing women's involvement in their communities and building their networks. The benefits of climate resilient roads for social capital were also found to apply particularly to women, which may also have been complemented by the encouragement of their involvement in MMCs.

6.1.8 Implications for the overall process of inclusive rural transformation

While not achieving large-scale livelihood shifts at the point that the research was conducted, we do find that improved rural infrastructure can help to catalyse inclusive rural transformation processes under the right conditions. For irrigation, better water supply, and supporting institutions, can help to increase agricultural and livestock productivity, and promote households to invest in a more lucrative mix of on- and off-farm activities, complemented in a virtuous cycle by improvements in assets, social capital and household nutrition. However, we find that catalytic impacts on the transformation process can be hindered by a lack of impact on production efficiency, and limited uptake of post-harvest technologies. This particularly applied to households who were induced to specialise in rice production, rather than diversify, due to connectivity constraints. This limited their income gains from specialisation, which limited the re-investment effect that is crucial to the transformation process. This lack of re-investment also applied to non-economic components, thus limiting the potential snowball effect caused by the interlinkages between the components.

In the case of markets and roads, these were found to have catalytic impacts driven by increased production efficiency, and sales profits, suggesting that transformational effects can be achieved without necessarily increasing farm output. Key to this mechanism were the closer proximity of markets that were usable year-round and supported by effective local institutions. However the ability of the project to promote more modern and lucrative on- and, particularly, off-farm activities for the poorest households in the project areas were limited due to a lack of access to inputs and skills, as well as limited re-investment in asset accumulation. Our analyses also find that more could also be done to spur transformational effects by promoting opportunities for self-employment and waged labour, and investment in technology. Finally, inconsistent impacts on dietary diversity, social capital and education suggest that the transformational effect of this type of infrastructure may be slightly unbalanced and limited to the economic sphere.

In terms of the inclusivity of the transformation process, as mentioned above, these effects are patchy, with uneven impacts of irrigation for downstream households and women, and for landless households and women from the market and road project. Based on this, the results highlight the risk of promoting an unequal transformation process unless further support is provided, as discussed further below.

While difficult to fully assess the sustainability of the impacts on the wider transformation process, we take some insights from the impacts on income diversity and asset ownership. Particularly for the market and road project, the lack of re-investment in assets could threaten the sustainability of impacts by leaving beneficiaries vulnerable to shocks. Similarly for the irrigation project, limited impacts on livelihood diversity for some households could have the same effect. This vulnerability is important, not only for when shocks occur, but also as it may hinder re-investment over the long-term due to higher risk aversion. Finally, sustainability of transformational impacts may be hindered by the limited inclusivity of the impacts in some cases. In particular for the market and road project, the lack of impact on the economic inclusion of women has the scope to severely curtail the transformation process in the long-term by limiting the economic potential of a large share of the population and hindering efficient allocation of labour which is a key mechanism within the process.

6.2 Contributions to the literature

This thesis provides nuanced views to the existing literature, fills evidence gaps, and offers several methodological contributions.

In terms of nuanced views, we highlight the need to delve further into the well-established positive link between rural infrastructure and agricultural productivity. In terms of irrigation, while confirming its strong positive impact on yields found elsewhere (see Lipton et al., 2003; Hussain and Hanjra, 2004; Pinstrup-Andersen and Shimokawa, 2006), our Meta-Frontier efficiency analysis highlights that impacts can be driven by increased investment and input use, rather than increased efficiency. Existing literature often struggles to explain why higher yields from rural development projects are not always converted into higher incomes—see for example Gordoncillo (2012) on the impact of land reform in the Philippines or a study by the World Bank (2008) on an irrigation project in India–and it may be that this lack of improvement in farming efficiency (and thus profitability) is the missing link.

In terms of evidence gaps, we contribute in several areas with regard to the impact of improved rural infrastructure. For instance, we offer scarce evidence on the impact of rural infrastructure on social capital, where we uncover an unexpectedly strong impact of rural roads, and of strengthened local institutions tasked to manage the infrastructure. On the understudied link between rural infrastructure and women’s empowerment, we offer new insights on the heterogeneous effects that this infrastructure can have on the economic and social inclusion of women, confirming the suspicion that infrastructure may be insufficient for some indicators and contexts to overcome the barriers they face (Asher and Novosad, 2016) and highlighting the need to consider the gendered impacts of infrastructure on women in future studies. The differential impacts we find for Muslim households reflects similar findings for a business training programme in India (see Field et al., 2010) and should be taken into account in future impact evaluations.

We also provide new evidence on the link between improved irrigation infrastructure and nutrition through the mechanism of enhanced livestock production. Not only does this address a well-known knowledge gap on how best to enhance livestock production in rural areas (Serra et al., 2020), it also adds evidence to support the link between enhanced livestock production and nutrition which was previously under-researched (McKune et al., 2020), with this impact pathway between irrigation and nutrition offering a fertile area for further investigation. Through our sub-group analyses, we also add empirical evidence to confirm the importance of contextual factors including market connectivity and supporting institutions, that hitherto have been largely theoretical in the literature (see Namara et al., 2010; Freguin-Gresh et al., 2012; Starkey and Hine, 2014; FAO, 2017).

We also contribute the first known impact evaluation of a project that built both climate resilient markets and market-connecting roads, expanding the evidence base from an exclusive focus on all-weather roads. Our findings confirm the until-now largely theoretical assertion that the type and package of infrastructure is important in shaping impacts (see van de Walle, 2009; Chowdhury, 2010; Hansen et al., 2011) showing that there are marginal benefits to climate-proofing infrastructure, and that combining road and market infrastructure can magnify impacts in some areas, while some indicators are only impacted by one of these. Also the fact that our findings differ by proximity to the infrastructure highlights the need to consider proximity in future impact studies, as well as the value of using GIS data in defining proximity, building on the work of BenYishay and Tunstall (2011) among others.

In terms of methodological contributions, our findings in Chapters 3 and 5 highlight the value of combining impact evaluation and SMF techniques. In both chapters our results indicate that increased yields found in past impact evaluations may have missed underlying mechanisms for how these improved yields were achieved (i.e through inputs input use rather than improved farm management). Our findings also indicate that past analyses using SPF methods to determine project impacts may have suffered from unaddressed selection bias. This highlights the need to reconsider how we interpret the findings of these past studies.

We also offer methodological contributions in adding to the growing body of literature employing the best-practice SMF methodology to compare the efficiency of sub-groups, which our results show differs notably from the traditional SPF approach. In doing so we build on rare examples from Alem et al. (2018) and Lawin and Tamini (2019). By analysing the effect of climatic shocks temporally—and finding interesting contrasts between recurrent and one-off shocks that are shaped by differences in coping strategies—we highlight the value of considering different types of exposure to such shocks. In uncovering the important role of coping strategies in shaping the impacts of projects focusing on climate change adaptation, we highlight a key area for further investigation whereby effects on coping strategies are investigated using datasets with a more explicit focus on household level coping strategies.

Finally, a further methodological contribution is our application of a new framework of indicators designed to assess impacts on inclusive rural transformation. In finding that projects' impacts on agricultural productivity, income, assets and other indicators of inclusive rural transformation do not always go in the same direction, we show that the common practice of focusing on projects' impacts on agricultural production and farm income may not tell the full story of their short- or long-term impacts. This insight likely applies to all types of rural development project, as supported by a systematic review of evidence on land tenure projects that also found impacts to differ considerably according to the dimension of the indicators (see

Higgins et al., 2018). As with the TE findings, this should be taken into account both for future impact evaluations of rural development projects, and in interpreting the results of past studies that apply a narrow set of indicators.

6.3 Implications for development policy and practice

Finding effective ways to foster inclusive rural transformation will be key to meeting the SDGs by 2030, and there are several implications that we can draw from the findings to inform ongoing policymaking and investments with this aim.

In terms of higher agricultural productivity, and subsequently profits, and our findings show that improving rural infrastructure in isolation may not always be sufficient to activate this mechanism within the rural transformation process consistently. Impacts on profitability, in particular, seem often to be hindered by a lack of improvement in production efficiency, which is a concern given the ongoing rise in land and water scarcity (USGCRP 2017; IPCC, 2019).

To increase profitability, and to promote sustainable input use amid growing scarcity, our results point to the need for complementary support to help to improve farm management, access to inputs, and market connectivity. Reviews of the evidence show that farm management can potentially be improved through extension services and FFS (Kahan, 2007; Waddington et al., 2014) and better information sharing (as discussed further below). Based on our findings, supporting access to inputs must chiefly address supply and affordability issues, which could be achieved by promoting linkages between local markets and broader market networks and supply chains, and by improving access to credit on favourable terms (taking care to align repayment schedules with agricultural seasons) (Dorward et al., 2008; Lipper et al., 2010; Langyintuo, 2020). In terms of credit access, future rural infrastructure projects should try to capitalise upon the wave of investments and innovations in digital technologies to improve access to rural financial services (World Bank, 2015; IFAD, 2019c). Finally, given the high profitability of agriculture thanks to better market proximity in Bangladesh, but limited profits where connectivity was weak in the Philippines, future projects must consider during the scoping phase the presence (or absence) of markets that are close, vibrant and with low transport costs, and to incorporate this into the project design accordingly.

Based on our findings, promoting lucrative on- and off-farm opportunities that are representative of a transforming rural economy must focus on finding and enhancing activities that have existing potential. This is demonstrated most notably in the irrigation case study, where we find that improved water supply can be very beneficial for livestock rearing, helping income from this source to double in project areas where livestock value chains were already developed. This indicates that the design of future infrastructure projects should be informed by mapping of local value chains to help identify on- and off-farm activities with potential to be enhanced through better infrastructure (Best et al., 2005). Based on the issues identified in our case studies, complementary support to target these identified activities can then be provided to address market information constraints, or promote connections with rural or urban markets (Marter, 2005; FAO, 2017).

On livestock production, furthermore, future policies and projects should seek to capitalise on the strong link that we uncover between livestock production and nutrition. As well as being a key component in the rural transformation process (especially in the longer term), improved nutrition is key to meeting the SDGs, and there is an ongoing push to make rural development projects more nutrition-sensitive (McKune et al., 2020). But despite this push, the role of livestock production has so far been largely ignored; something that was already considered as a missed opportunity (McKune et al., 2020), and appears even more so based on our findings.

Our results highlight that any policy or project aiming to promote inclusive, balanced and sustainable rural transformation must consider the role of local institutions. It has been suggested that investment in building institutions to stimulate development is often underprioritised because the benefits are not immediately apparent or measurable (Natsios, 2010). However, our results show that strengthening existing local institutions (such as IAs), or creating new ones (such as MMCs) can enhance project impacts in the short-term by ensuring that infrastructure built by the project is managed and maintained in a way that is equitable and sustainable after the project is over. Projects implementing climate resilient markets should in particular look to invest in local institutions to ensure the markets remain functional during and after climatic shocks. Scoping for new projects should therefore include a mapping of local institutions and their capacity and resource needs, and support to them should be incorporated into the project design. Policies can also help in some contexts by providing more responsibilities to these local institutions where they have the capacity and can be monitored accordingly (Agrawal et al., 2008).

Alongside improved roads, our findings show that activities to strengthen local institutions also seem to have a powerful effect on social capital—which could be used as a powerful mechanism to enhance rural transformation impacts of future policies and projects. For instance, as mentioned above, a key constraint to the impacts of rural infrastructure on agricultural production and profitability is weak input access, and as demonstrated in a range of contexts (see FAO, 2012c), strong local institutions and collective action can help to overcome these challenges, particularly in terms of providing micro-lending, cost-sharing or collective bargaining functions. These benefits could also enhance advancement into lucrative on- and off-farm opportunities. Future projects could also leverage this link to promote information-sharing that could help to address the lack of improvement in farm management that also hindered the impacts of our two case study projects. Lipper et al. (2010) recommend that local institutions be strengthened to verify seed sellers, and provide information to buyers on their quality and use. Finally, strengthened local institutions could help to add another layer of protection from both climatic and non-climatic shocks—the latter most notably was not always strengthened in our case studies—by facilitating risk sharing and offering social protection services (Adger, 2003).

While strengthening local institutions like IAs can help, our findings indicate that improving the inclusivity of rural transformation through rural infrastructure requires further targeted support to the poorest beneficiaries. This targeted support must address the input access issues outlined above (from which they disproportionately suffer), as well as the specific barriers they face to progressing into off-farm activities. Based on our findings, advancement into off-farm activities for the poorest, with the help of improved infrastructure, can be enhanced with complementary skills training and access to credit. This can encourage and facilitate the investment of the poorest beneficiaries in activities more representative of a transforming rural economy, whether that is increased specialisation in high output, high profitability farming, or lucrative off-farm opportunities (Alobo Loison, 2015; FAO, 2017).

Based on our findings, increasing the economic inclusion of the poorest rural women requires another layer of tailored support. Highlighted by our findings from public works employment through LCS in Bangladesh, and evidenced elsewhere, women face challenges both in finding, and in keeping employment, especially off the farm (Bezu and Barrett, 2012; Fuje, 2017; Djurfeldt, 2018; Van den Broeck and Kilic, 2019). An effective complementary support could be informed by BRAC’s Empowerment and Livelihood for Adolescents approach (implemented in seven countries to date), which has proven effective at improving women’s hard and soft skills through sessions held in a safe space environment and involving men and other community members, thus helping to develop women’s skills as well as promoting dialogue about the position of women in households and the community (Bandiera et al., 2018; Arslan et al., 2019). In addition to training, the impact of future rural infrastructure projects on women’s inclusion could be boosted by leveraging the strong link we uncover between roads, institutions and women's social capital, especially in contexts such as Bangladesh where other channels to improve women's economic inclusion are heavily constrained.

Finally, with regard to investing in ways to ensure that the effects of climate change do not derail rural transformation processes, our results confirm the incremental benefits of ensuring infrastructure is climate proof. To make these investments even more worthwhile, our results suggest that future projects could also promote the purchase of resilience-enhancing assets, which are key to long-term climate change adaptation (IPCC, 2014). We also find evidence that promoting the production of a specific crop through these projects could increase the risk of crop-specific shocks. The recommendations above for more efficient production can help to protect farmers from these shocks in cases where increased specialisation makes sense. Where it does not, efforts should be made during project design to avoid this specialisation by securing access to inputs and information for producing other crops, and fostering beneficial market linkages for a wide range of crops (Thornton et al., 2019; Kruseman et al., 2020).

6.4 Limitations of the thesis and challenges for future research

As noted in the introductory chapter, a key constraint of this research is that it is based on cross-sectional data, with the lack of baseline data potentially hindering the ability to reliably control for selection bias between treatment and control households. However, we have shown that using a sophisticated sample design, and employing GIS data, can help to identify well-matched treatment and control households who can then be treated further for selection bias using econometric techniques. The main challenge, as with all ex-post impact evaluations, is that we have only been able to reduce selection bias based on observable characteristics. While robustness checks confirm that we were able to reduce selection bias on observables to a negligible level, the risk remains of bias based on unobservables. To combat this we cross-check the results using qualitative data, and we do not find instances where the qualitative data contradicts the quantitative findings, which suggests that any bias on unobservables is unlikely to have influenced the results. Similarly we find that results are qualitatively similar in all the analyses when different models are applied, another indicator of the validity of the results. The reliability of our findings is also helped by a healthy sample size in both cases – derived from best-practice sample calculations – although we do run into sample size issues when breaking down the sample for some of the sub-group analyses, such as for education impacts in Chapter 2 and for certain livelihood impacts in Chapter 4.

Based on the sample size issue, a key area for future research is a more focused study of the impact of improved rural infrastructure on education. While included as an indicator in the impact frameworks of some other rural infrastructure studies—such as Aggarwal (2018) in India and Ring et al. (2018) in Madagascar—more evidence on impact pathways is required given the importance of this indicator to inclusive rural transformation in the long-term (IFAD, 2016). Other insights from this thesis also warrant further investigation through focused studies, including the promising connections between irrigation, livestock production and nutrition; and between all types of rural infrastructure and social capital. Detailed modelling of the influence of our case study projects on coping strategies was out of the scope of this thesis, but our indication that climate resilient infrastructure can help to avoid negative coping strategies should be followed-up, informed by the methodologies employed by Béné et al. (2020) and Béné and Haque (2021) on resilience-building projects in Niger and Bangladesh, respectively. Finally, given our research is applied to just two countries, the inclusive rural transformation framework should be applied to rural infrastructure projects in other countries in order to grow the evidence base and further inform policy.

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Summary

Finding effective ways to foster inclusive rural transformation in developing countries is key to achieving the Sustainable Development Goals. Improving rural infrastructure has the potential to impact the transformation process in many ways, including by enhancing agricultural productivity, off-farm activities, asset accumulation, resilience, food security and nutrition, social capital, and investments in education. It also has the potential to improve the inclusion of women and other marginalised groups in the transformation process. Aiming to fill evidence gaps and to inform policy, we test these potential impact pathways using two rural infrastructure projects in Bangladesh and the Philippines. In order to draw more nuanced policy implications, we particularly focus on the contextual factors that may have influenced the impacts of the projects.

The first two chapters are focused on the Irrigated Rice Production Enhancement Project (IRPEP) in the Philippines. Implemented by the International Fund for Agricultural Development (IFAD), the project aimed to improve canal irrigation systems for smallholder rice farmers, as well as building the capacity of local Irrigators' Associations to manage them. The next two chapters are focused on the impact of the Coastal Climate Resilience Infrastructure Project (CCRIP) in southwest Bangladesh. Also implemented by IFAD, this project built and improved small rural markets and market-connecting roads to make them usable year-round, including during seasonal flooding, and also built the capacity of local Market Management Committees to ensure markets are managed sustainably.

Sets of quantitative and qualitative data were collected for each of the projects. The quantitative datasets consist of both beneficiary and control households, and the samples were designed in order to ensure that, for each project, these two groups of households were comparable, with a low risk of selection bias that could distort the impact estimates.

In Chapter 1 we analyse the impact of IRPEP using a framework of inclusive rural transformation indicators and a statistical matching analysis to compare treated and control households. While we find strong positive impacts on rice yields, we find that impacts on other aspects of the transformation process were heavily influenced by market access and whether the local economy was structured to support lucrative livelihood diversification. Where this was the case, we find a particularly strong link between improved irrigation and livestock production. While poorer downstream farmers benefitted in terms of better yields, broader transformational impacts for this group were curtailed by limited access to inputs and markets. Finally, we find that strengthening Irrigators' Associations was particularly effective in promoting women's inclusion and equitable water use along the canals.

In Chapter 2 we further explore the impacts of IRPEP on agricultural productivity, using a Stochastic Meta-Frontier approach, combined with impact evaluation techniques, to assess how the project affected the Technical Efficiency and Frontier Output of beneficiaries at the parcel level. Broadly, we find a strong impact on Frontier Output, suggesting that improved irrigation technology helped to increase production potential, but this was coupled with limited impacts on Technical Efficiency, suggesting that farm management was not improved, highlighting the need for more support in this area in future projects. Analyses for various sub-groups suggest that the project had a pro-poor impact, potentially enhanced by the role of the Irrigators' Associations in promoting more equitable water use.

Similar to Chapter 1, in Chapter 3 we apply a framework of inclusive rural transformation indicators to assess the impact of CCRIP using a similar statistical matching approach. We find that the project had limited impacts on agricultural production, potentially as beneficiaries were unable to afford the required inputs, but thanks to higher prices and a higher proportion of harvests being sold, agricultural income increased substantially. That this income effect applied to both the dry and monsoon season indicates that the flood-proofing of the market and road

infrastructure served its purpose, for which the role of the Market Management Committees was reported to be crucial. Impacts on income and livelihood diversification were mixed, and while the poorest sub-group experienced the highest impact on total income, advancements into some off-farm livelihood activities may have been hindered by limited education and skills for this group. Other key findings include a strong impact on social capital driven by the improved roads, but limited re-investment of income into assets, leading to concerns about resilience to shocks in the future. The impact on social capital was especially pronounced for women, but we find limited impacts on their economic inclusion due to restrictive social norms.

Similar to Chapter 2, in Chapter 4 we conduct a more granular analysis of the impacts of CCRIP on agricultural productivity using a Stochastic Meta-Frontier impact evaluation approach. We find that Frontier Output was only improved for those with low exposure to floods, implying that the impact of climate-resilient infrastructure on production potential—expected to be achieved by improving access to inputs—may have continued to be hindered by flooding. We also find that Technical Efficiency increased only for those exposed to recurrent floods over time, indicating that, compared to the control group, these beneficiaries were able to consistently avoid reverting to coping strategies that hindered their farm management in the face of these recurrent shocks.

The concluding chapter summarises the findings for the various components of inclusion rural transformation and draws implications for the impacts of the two projects on the overall transformation process. We note that irrigation can be very effective at advancing both the economic and social aspects of the transformation process in project areas with strong market access and a conducive local economy. Climate resilient markets and roads, on the other hand, mainly contributed to the economic aspects of the transformation process (with the exception of social capital), which were achieved with limited impacts on agricultural production, which is the historic driver of the transformation process. In the case of both projects, the

strengthening of local institutions to manage the infrastructure played a key role in their impacts, especially in promoting inclusion of women and the poorest households, although overall impacts on the economic and social inclusion of these marginalised groups was patchy, which may have implications for the sustainability of the transformational progress catalysed through the projects.

In the concluding chapter we also offer some implications for the literature and for development policy and practice. For the literature we highlight the need to go beyond analysing impacts on crop yields when assessing the impacts of rural development projects, as well as highlighting the value of combining Stochastic Meta-Frontier and impact evaluation techniques. Links between improved rural infrastructure and livestock production, and impacts on coping strategies, are noted as interesting areas for future research. In terms of development policy and practice, among other points, we highlight the need to leverage the value of local institutions in enhancing the impact of rural development projects, and to map pre-existing market access and account for this in project design.

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