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WHAT IS THE IMPACT OF INFRASTRUCTURAL INVESTMENTS IN ROADS, ELECTRICITY AND IRRIGATION ON AGRICULTURAL PRODUCTIVITY?

Systematic Review

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Summary

Infrastructural services including roads, electricity, telecommunications and irrigation, are all considered to be of major importance in stimulating agricultural investment and growth. However, their existence is still very limited in most rural areas of many developing countries. Whilst there exist much information in the scientific and grey literature on the issues relating to infrastructural impacts on agricultural development, there is no recent, objective, and independent review of the available evidence. The research question for this systematic review was therefore to assess "What is the impact of infrastructural investments in roads, electricity and irrigation on agricultural productivity?"

This systematic review summarises the research objectives, approaches and methods, including the search criteria, data sources, search and extraction strategies, data synthesis, analysis and interpretation. The systematic review principally focussed on four main areas (i) road infrastructure (incorporating road networks and transport vehicles) and its impact on farmer access to agricultural markets; (ii) rural electricity supplies (consumption and expenditure) and its impact on agricultural productivity (irrigation, storage, cooling/refrigeration), product price, labour wages and rural GDP; (iii) telecommunications (telephones and internet) and its impact on crop prices, response to market demands, feed and fertilizer supply and costs, and (iv) irrigation infrastructure (incorporating water storage capacity per unit area, access to water and expansion of irrigated areas) and its impact on crop diversity, crop productivity (yield), crop prices, labour costs, rural consumption and returns of irrigation investment to the rural community and poverty reduction.

Following definition of suitable search terms and study inclusion/exclusion criteria, a detailed search of available evidence was completed using a range of scientific bibliographic sources and internet websites. In total, 934 articles were identified, and then screened by title and abstract to provide a final listing of 155 articles and reports. These were imported into Refworks and analysed. Data were presented on the basis of a narrative synthesis but supported by quantitative analysis, based on an aggregation of reported observations and using simple impact assessment classification (positive impact, neutral impact and negative impact). An attempt was made to undertake some meta-analysis based on 307 observations, but this was not possible given the wide range of units reported in the literature, even within a particular impact indicator, and the impact of various 'effect modifiers'.

A narrative synthesis by infrastructural impact was therefore completed first, with evidence aggregated by country, where possible. Tables summarising the reported effects on agricultural productivity were produced for a range of productivity/output indicators. Next, a quantitative analysis using the 307 'observations' was completed. From the evidence, it was apparent that a wide range of indicators had been used to assess the impact of investment in rural infrastructure on agricultural productivity. These were categorised into 9 main classes (i) agricultural productivity (measures of crop yield and output per unit area), (ii) consumption (measures of rural consumption and expenditure), (iii) GDP (measures of changes in total or rural GDP), (iv) income (measures of rural income, crop revenues and gross margins), (v) inputs (measures prices, demand, use and supply of agricultural inputs including seeds, fertilisers, fuel, labour and high yielding varieties (HYVs)), (vi) labour (measures of rural employment and wages), (vii) poverty (measures of the number of people in poverty,

(viii) prices (measures of process of agricultural outputs) and (ix) production (measures of the quantity of production of crops and livestock).

For road infrastructure, most evidence (37% observations) related to this investment, with the majority of reported impacts on agricultural productivity being positive, particularly in relation to GDP gains and poverty reduction. For electricity infrastructure, there was limited evidence (16% observations) but again positive, especially for poverty reduction. For telecommunication infrastructure, there was very limited evidence (6% observations) but the majority were positive. The impacts for this area are most likely to be mixed in with other forms of infrastructural investment. Finally, for irrigation infrastructure, a third of all evidence related to this aspect, with the majority of impacts on agricultural productivity being positive, especially in relation to income and poverty reduction. The SR also identified some important gaps in knowledge on the direct impacts of investment in electricity and telecommunications infrastructure on agricultural productivity, and a number of methodological limitations due to 'effect modifiers'. This may not be surprising given that these types of investment are difficult to examine in isolation. Finally, the review has generated significant new aggregated data on infrastructural impacts on agricultural productivity which should be of broad international relevance to those engaged in assessments of agricultural and rural development.

Keywords: rural; infrastructure; roads, transport; electricity; irrigation; agriculture; productivity; crop; yield

1. Background

In many regions of the world, agricultural productivity has more than doubled since the 1960s in response to the introduction of synthetic fertilisers, pesticides, genetic breeding and irrigation (Hanjra *et al*., 2009a) as well as supportive policies and institutional infrastructure (Namara *et al*., 2010). But despite food becoming cheaper and more plentiful, the global food system is expected to experience an unprecedented confluence of pressures over the next 40 years. On the demand side, global population is expected to increase from nearly 7 to over 9 billion by the 2050s; many people are likely to be wealthier, creating demand for more varied, high quality diets requiring additional resources to produce (Hanjra and Qureshi, 2010). On the production side, competition for land, water and energy will intensify, while the effects of environmental degradation and climate change are likely to exacerbate the current situation (Khan and Hanjra, 2009; Nellemann, 2009; Beddington, 2010; Foresight Report, 2011).

There is currently significant variation in global agricultural productivity. The International Water Management Institute (IWMI) reported that bringing production levels of the world's low-yield farmers up to 80% of that attained by high-yield farmers from comparable land, would provide three quarters of the additional food demand needed over the next few decades (IWMI, 2007). In this context, better water management will play a key role in bridging that 'yield gap' (the difference between actual and potential yields) (Molden *et al*., 2010). But achieving such increases in productivity is fraught with difficulty and closing the 'yield gap will not be easy. Although improved crop agronomy and plant breeding will play critical roles, both in rainfed and irrigated crop production, so too will infrastructural services that underpin and support agriculture, including electricity supplies, road networks and irrigation. Improved productivity will thus depend not only on better resource efficiency (e.g. fertiliser and water) but it will also need to be supported by improved access to resources and markets (e.g. development of rural road networks) and infrastructure (e.g. electricity).

In many developing countries, agriculture is the cornerstone of the economy, the basis of economic growth and the main source of livelihood (Wheeler and Kay, 2010). It is a major contributor to their economies, not only in their gross domestic product (typically ≈25%), but also in merchandising exports (≈ 21%) and most significantly employment (≈60%) (World Bank, 2010). Even though the importance of agricultural development for building economic growth and alleviating poverty in developing countries cannot be ignored, its relative contribution to the economy decreases as the prosperity of a country develops.

Providing support to increase the agricultural productivity of many developing countries (mainly Africa and South East Asia) seems one of the most sensible ways to ensure greater food security and alleviate poverty (Ali and Pernia, 2003; Hanjra and Gichuki, 2008). Increases in agricultural productivity (per unit of land and/or unit of labour) lead to income benefits for the rural poor, ultimately enhancing their purchasing power and demand for other goods and services. Low food prices achieved by reducing the costs of production also contribute to lower wages in non-agricultural sectors thus facilitating industrial growth (Pinstrup-Andersen and Shimokaya, 2006). In addition, agricultural growth can have positive impacts on downstream activities beyond the farm gate (Hussain and Hanjra, 2003; Hussain and Hanjra 2004);

including processing, post-harvest storage, manufacturing of agricultural equipment, tools and inputs, storage industries and distribution.

Agricultural output is determined in a complex interactive process whereby farmers, governments and intermediaries all respond to the same factor (Biswanger, 1993). Farmers respond to infrastructure, governments in turn allocate their infrastructure investments in response to the agroclimatic potential of the district and banks locate their branches where the infrastructure and agroclimate are most favourable to their operation (e.g. Binswanger and Khandker, 1995).

Agricultural development also requires increasing the access to a range of services (e.g. finance, raw materials and resources) and providing the means to store, distribute and market agricultural goods. The investment in basic infrastructure - such as suitable transportation, affordable communications and reliable power generation - are all pre-requisites for a successful agricultural-driven economy (NEPAD, 2002), but in many developing countries these basic necessary conditions for economic development are still lacking.

Transport helps in linking rural areas to aggregate growth. Since the majority of the rural workforce in most developing countries are directly, or indirectly, dependent on the agricultural sector for employment, expanding the road network and improving road maintenance in rural areas can directly translate into lower transport costs for inputs (such as fertiliser) and market outputs, since it reduces the travel times for delivery to market and reduces the frequency of transport damage (e.g. vehicles and produce). Gaining improved access to markets also helps farmers to achieve greater consumer demand for their produce. Both lower transport costs and higher demand raise the margin between sales prices and production costs, resulting in higher incomes and consequent welfare improvements for the rural population (GTZ, 2005).

Investment in irrigation infrastructure can also contribute significantly to agricultural growth as it can help to widen the production options, increase yields, improve quality and help stabilise market supplies by mitigating the effects of drought and reducing inter-seasonal variability in output and economic activity (Hanjra *et al.,* 2009a; Hanjra *et al.,*2009b).

Better communications between exporters and importers (transport and telecommunication) allows more timely and safe delivery of goods in response to market demand, thus improving an agricultural sectors' competitiveness (Pinstrup-Andersen and Shimokaya, 2006).

These infrastructural services (i.e. roads, electricity, telecommunications and irrigation) are all of key importance in stimulating agricultural investment and growth but are still limited in most rural areas of many developing countries (FAO, 1996). In these regions, transportation costs are generally high, productivity is low and the supply of basic inputs and electricity is unreliable, thus reducing the price competitiveness of those countries in international markets. Africa, for example, has one of the lowest road densities in the world - a third of its population live in landlocked countries with poor access to global markets. For example, it is estimated that it typically takes an African exporter about 40 days to reach and cross the border into a neighbouring country compared with only 22 days for a Latin American counterpart (World Bank, 2009). However, the quality of infrastructure is as important as its presence (Fan and Chang-Kang, 2005) due to its implications on the speed of transit and transport costs (which are cheaper for paved roads and more

stable compared to those for unpaved roads which are costly and vary significantly from season to season).

The absence of spatial and temporal market integration is also a common issue in many low-income countries and is primarily linked to poor agricultural infrastructure and missing markets. This often results in an increase in market supply and drops in local prices in areas of favourable growing conditions, in contrast to other areas which may suffer from deficits in supply and price increases (Pinstrup-Andersen and Shimokaya, 2006).

This systematic review report defines the framework for the systematic review of the impact of infrastructural investments in roads, electricity, telecommunications and irrigation on agricultural productivity, including the research objectives, the data searches and extraction strategies used and the approaches for data synthesis, analysis and interpretation. The review has broader international relevance to those engaged in assessments of infrastructure impact on agricultural productivity and rural development.

2. Objective of the Review

As in all systematic reviews, one of the most important aspects is formulating the primary question, which is inevitably a compromise between taking a holistic approach, involving a large number of variables and relevant studies, and a reductionist approach that limits the review's relevance, utility, and value. The subject of infrastructure impact on agricultural productivity falls into the former category as the literature is vast and the results very likely to be biased by various endogeneities and externalities. Therefore, this systematic review principally focussed on the following four main areas:

1. Road infrastructure (incorporating road networks and transport vehicles) and its impact on farmer access to agricultural markets. In this context, the whole road network is critical – feeder road projects are often linked into poorly maintained and degraded secondary/primary roads and their agricultural impact can diminish as a result;
2. Rural electricity supplies (consumption and expenditure) and its impact on agricultural productivity (irrigation, storage, cooling/refrigeration), product price, labour wages and rural GDP;
3. Telecommunications (telephones and internet) and its impact on crop prices, response to market demands, feed and fertilizer supply and costs, and;
4. Irrigation infrastructure (incorporating water storage capacity per unit area, access to water and expansion of irrigated areas) and its impact on crop diversity, crop productivity (yield), crop prices, labour costs, rural consumption and returns of irrigation investment to the rural community and poverty reduction.

Thus the primary research question for this systematic review (SR) was:

"What is the impact of infrastructural investments in roads, electricity, telecommunications and irrigation on agricultural productivity?"

Following SR convention, the research question needs to be broken down into components (PICO/PECO) (Table 1).

Table 1 Breaking down the research question (PICO/PECO).

Component	Description
Population	Agricultural and rural communities including farming businesses at field, district and national level in developing countries. Agriculture includes both 'food' (cropping and livestock) and 'non-food' (fibre, industrial, timber) crops for both internal consumption and export.
Interventions	Transport networks (road density and quality, all weather road access and transport means); Irrigation infrastructure (e.g. canals, groundwater access, water storage capacity, tube wells, piped water and treadle pumps) Infrastructure development – including buildings for post-harvest storage, processing, cooling and refrigeration; Rural electricity supply networks (expansion of coverage area, new energy sources, supply reliability); telecommunications including telephone (landline and mobile), faxes and internet access
Comparators	'Before' and 'After', 'With' and 'Without', 'More' and 'Less' intervention
Outcomes	Poverty reduction, agricultural wage, transport cost, agriculture and rural GDP, labour productivity, changes in cropped area, irrigated area, agricultural productivity, food /crop price, fertilizer input, high yielding variety (HYV) use, energy and agricultural input consumption.

3. Methods

The SR protocol was drafted, revised and finalised in Autumn 2011 (Knox, J.W, Daccache, A. and Hess, T.M (2011). What is the impact of infrastructural investments in roads, electricity and irrigation on agricultural productivity? CEE protocol 11-007. CEE: www.environmentalevidence.org/SR11007.html). A scoping study was then undertaken to test the search strategy and gauge the scale of available literature based on the agreed search terms. The full SR commenced in October 2011 and was completed in May 2012. Following peer review, the SR was then updated and finalised in December 2012. The methodology used for this systematic review is summarized below.

3.1 Searches

A series of searches were trialled using Scopus (Table 2) with the aim to select a search term that is not too broad (exhaustive and time consuming) and not too restrictive (risk to not capture all the relevant articles). Accordingly and following consultations and agreements between the reviewers, the string used to search in the "Title" and "Keywords" of the database sources and organisation websites listed in Table 3 was the following:

"Agricultur* or Rural) AND (Infrastructur* OR Road OR Electric* OR Irrigat* OR Transport*) AND (Econom* OR develop* OR Poverty OR Growth)"

Table 2 Search terms trialled in Scopus (7th Sept 2011) and number of hits (* and ? denote wildcards).

Search term	All in title	All in topic	Comment
Agricultur* AND (Infrastructure OR Road OR Electric* OR Irrigat*)	778	25,631	Search term too broad but includes all the potential information that might be relevant to this SR
Agricultur* AND (Infrastructure OR Road OR Electric* OR Irrigat*) AND (Rural OR developing countr*)	2	1,732	This limits the research to the interested areas (rural areas and developing countries). This search term is not geographically restricted
Agricultur* AND (Infrastructure OR Road OR Electric* OR Irrigat*) AND (sustainabil* OR Environment*)	52	8,838	This search focuses on the environmental impacts of infrastructural development or the agricultural production sustainability aspects
Agricultur* AND (Infrastructure OR Road OR Electric* OR Irrigat*) AND (Poverty OR Employment OR social OR Education OR Econom* OR development OR Price)	81	10,509	This search is too broad and covers the infrastructural development impacts on the socio-economic situation of rural areas
Agricultur* AND (Infrastructure OR Road OR Electric* OR Irrigat*) AND (Product*OR Yield OR "Food security")	56	11,841	This search includes all the potential impacts of infrastructural investment on agricultural productivity

Table 3 Database sources and websites.

Database sources	Search websites	Organisation websites
ISI Web of Knowledge (WoK)	Google.com	World Bank
Scopus	googlescholar.com	International Fund for Agricultural Development (IFAD)
ScienceDirect		Consultative Group on International Agricultural Research (CGIAR)
EBSCO GreenFILE		International Water Management Institute (IWMI)
CSA Natural Sciences Document Repository		Asian Development Bank (ADB)
Directory of Open Access Journals		African Development bank (AfDB)
FAO Corporate		Overseas Development Institute (ODI)

All references retrieved from the computerised databases (WoK, Scopus, etc.) were then imported into a bibliographic software package (Refworks) prior to assessment of relevance using inclusion criteria. The bibliographies of included material were searched for relevant references. The review was limited to the literature published in English - the scientific language of most of the international papers.

Searches were limited to sources published from 1990 onwards to reduce the effect of the large structural changes that occurred in many developing countries prior to this date. Even though the study was mostly relevant to Africa and South Asia, these key words and those of any specific countries were not used as search terms, as this may have restricted the search and excluded studies that have taken a wider perspective.

3.2 Study inclusion criteria

All articles retrieved were screened for relevance using the following inclusion criteria.

Relevant subjects

- Any agricultural sector (animal/crop/fuel/fibre);
- Any agricultural enterprise (individual farms, districts, agribusiness);
- Any country in the world (no geographical or economic development restriction), and;
- Any scale of analysis (national/province/village).

Types of intervention

- New transport network and/or improvement of existing ones (i.e. railroads, roads, urban transport, waterways and ports);
- Implementation/rehabilitation of hydraulic structures (i.e. dams, pressurized or open channel water distribution systems, pumps, weather stations);
- Power plant, distribution network, alternative energy sources (i.e. hydropower, wind turbine, solar panels), good quality and reliable energy supplies, and;
- Fast, good geographical coverage and reliable internet and mobile phone communications.

Comparators

Studies must have compared either the outcomes ‘before’ and ‘after’ the project implementation; compared the agricultural productivity of areas ‘with’ and ‘without’ certain types of infrastructure; or compared different geographical locations, population density, political stability and economic capacity.

Methods

Econometric analyses, post-investment appraisal reports, technical assessments (e.g. economic/engineering/financial institutions), case studies, sector analysis reports, academic studies and journal special issues comparing farming livelihoods/production ‘before’ and ‘after’ or areas ‘with’ and ‘without’ a certain type of infrastructure. Methods included cost-benefit analysis, Simultaneous Equation Model (SEM),

Quantile Regression (QR), Ordinary Least Squares (OLS), Generalized Method of Moments (GMM), and Principal Components (PC).

Outcomes

Impact on agricultural productivity (yield, total production, cropping area), agricultural input (fertilizer use, high yield variety adoption, irrigated area), labour (wage, employment), cost (crop price, fertilizer cost, transport cost, market access), rural development (agricultural and rural GDP, poverty reduction, consumption increase).

The initial filtering was undertaken based on the title of the literature source; a second filter was then based on the content of the abstract, and the full text was reviewed only for those articles, reports and papers that passed all inclusion criteria. This was undertaken by two researchers (Daccache and Knox) working independently to screen the literature datasets. A cross comparison was made to ensure consistency between the two researchers in the application of the inclusion criteria. Literature showing inconsistency of agreement between the two reviewers was discussed and analysed between them until a decision was agreed. A third reviewer was also consulted as required.

3.3 Potential effect modifiers and reasons for heterogeneity

Systematic reviews are generally best applied to studies where there is good primary data on the outcomes of treatments or interventions compared to a control. This review has assessed the outputs of a large number of studies, all of which inevitably contain a number of 'effect modifiers', including:

- Geographical location (which affects potential agricultural markets, opportunities for trade, competition and hence agricultural development); For example, Mozambique might receive more infrastructural investments than Malawi because it has an extensive coastline that can be used by landlocked countries;
- Initial infrastructure condition (e.g. absence of basic infrastructure, poor quality infrastructure, insufficient and/or unreliable);
- Availability of natural resources such as water, land and energy;
- Population density and population engaged in agriculture. For example, infrastructural investment may have a higher rate of return in South Asia than in Sub-Saharan Africa because the population density is higher;
- Endogenous program placement. For equity reasons, authorities might target infrastructural investments for less-favoured communities which might have a lower rate of return than the same investment for other communities;
- Efficiency of different political and financial institutions. Some countries are 'donor darlings' for historical, political or strategic reasons (or for having good governance and anti-corruption programs) and hence receive more investment than others;
- Conflicts and civil wars might freeze any external investment, lead to demolition of existing infrastructure and fleeing refugees;

- There a large number of studies in both the published and grey literature that analyse the impact of infrastructure on agricultural development. However, in most of the sources found, direct comparisons could not be undertaken because measurements of output and infrastructure investments were specific to each study;
- In addition, the impact of infrastructure on the agricultural sector varies between and across countries. When the endogeneity of infrastructure development is controlled, the effects of infrastructure tend to be smaller;
- Reverse causality from agricultural growth to infrastructure investment is another issue in these studies. When reverse causality is controlled, the effect of infrastructure on the agricultural development is underestimated (Fan and Zhang, 2004; Munnel, 1992);
- Some analyses focus on a particular element of infrastructure and ignore the effect of interaction among these elements. Moreover the approach used in these studies misses the indirect effects or externalities which are the major challenging task of any empirical study, and;
- Environmental limitations that limit infrastructural development such as negative impact on protected lands (natural reserves, national parks) or damaged ecosystems (over-exploited water resources, clearing productive areas, digging and removing valuable soils).

The extent to which these 'effect modifiers' are present in each reported study thus influences the robustness of the SR analysis, and presents an inherent limitation in the methodology. Hence a systematic review in its conventional form in this subject area is challenging; the outputs and conclusions need to be carefully interpreted.

3.4 Study quality assessment

To avoid bias, care was exercised in interpreting studies reporting infrastructural impacts across similar agricultural systems but using different methodologies, as there is no single discriminator that can be used to determine which model/approach is best. For example, contrasting economic assessment methods, definition of different key performance indicators, and the appropriateness of temporal and spatial scales, all have an impact on the reported outputs, and hence result in potential for bias where low quality (mainly rural) data might have been used. In other disciplines, a 'hierarchy of research methodologies' is typically used to score data in terms of its scientific rigour. This approach will strictly not work in this SR because the environmental-political-geographical context of each study provided too much 'internal' variability. In most cases, infrastructure development projects/assessment reports are intentionally conducted at a country level. These were compared to other studies taking into consideration the effect modifiers and potential sources of bias. The data was assessed against whether they used recognised econometric approaches, key performance indicators (KPIs) and data sources. Once the data was extracted and imported into the database (Refworks) a field was added to highlight whether the geographical location of the study, the time scale, the method used and if the effect modifiers are taken into consideration. Although qualitative research was included in the SR, the findings are primarily based on the objective quantitative data. The qualitative data was used to inform the narrative synthesis and statistical analysis.

3.5 Data extraction strategy

It was anticipated that a range of empirical data would be identified, ranging from detailed case studies (at county or regional level) to more broad-scale national assessments. The approach was to extract all relevant data based on the 'outcome' search terms and inclusion criteria, and then tabulate the information by variable and region using MS Excel. The data extraction process was carefully monitored, noting any reasons for data heterogeneity. The types of data found in the literature included a range of economic performance indicators (e.g. agricultural GDP, total GDP, product value, output per worker, and agriculture output.

3.6 Data synthesis and presentation

The data were presented mainly on the basis of a narrative synthesis but supported with some quantitative analysis, based on an aggregation of reported observations and using simple impact assessment classification (positive impact, neutral impact and negative impact). An attempt was made to undertake some meta analysis but this was not possible given the wide range of units reported in the literature, even within a particular impact indicator. This narrative approach is best suited to studies where the subject content is broad and the range of potential outcomes is disparate and the 'effect modifiers' dominant. It does, however, help to highlight gaps in knowledge, and where future programme investment might be most usefully targeted.

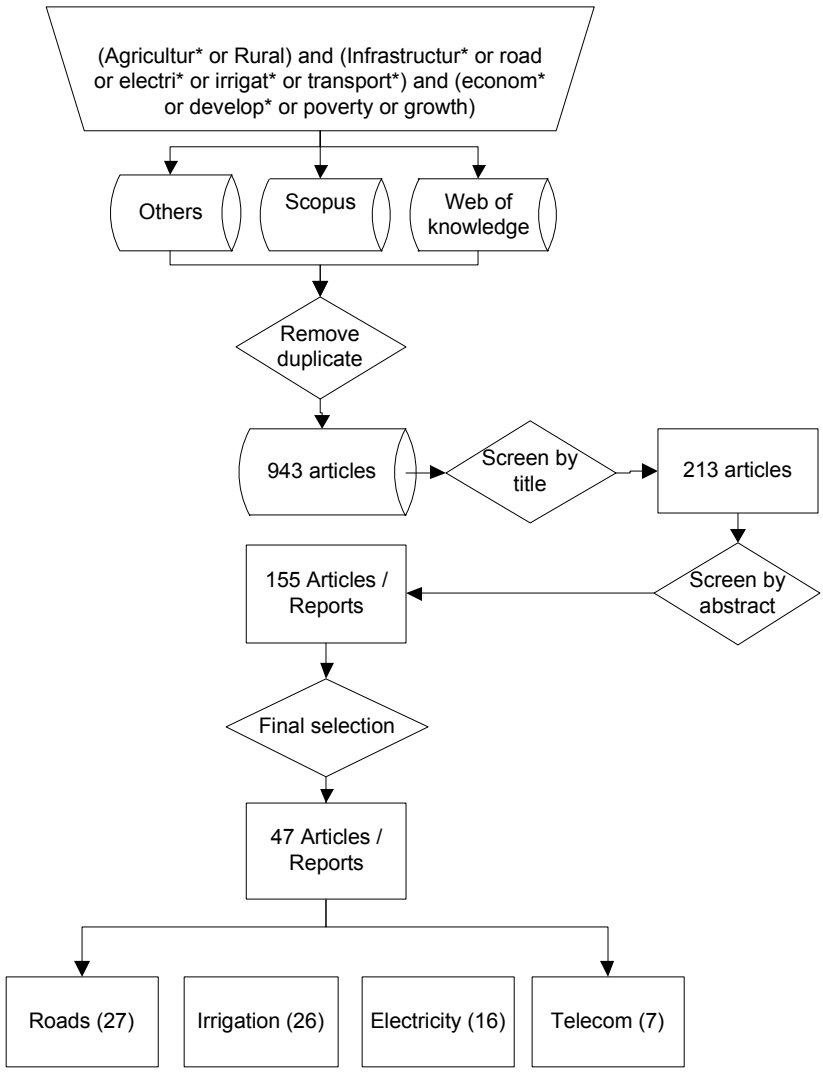
4. Results

4.1 Review descriptive statistics

The articles included in this work were selected and screened in five stages as shown in Figure 1 overleaf.

- Using the agreed keywords, databases and websites, the titles and keywords of the relevant articles (papers/reports/grey literature) were imported into reference database software (RefWorks);
- Sources might be found in different databases and for that reason duplicates were controlled and removed;
- A first screening of the sources was based on the title to remove those that clearly did not match the inclusion criteria;
- A second screening based on the abstracts and the report summary was performed thus reducing the number of relevant sources from 213 to 155, and;
- A final screening was performed based on the methodology and the findings of the paper/report.

Figure 1 Schematic overview of the individual stages in the systematic review.



Consequently, the number of relevant articles (reports, books and scientific papers) finally included in this SR is 47. Figure 2 summarises the number of relevant articles by publisher (journal/organisation). The most significant data source was the International Food Policy Research Institute (IFPRI) which had 10 relevant reports that fitted the SR selection criteria. The World Bank had 4 relevant articles. For peer-reviewed journals, the '*American Journal of Agricultural Economics'* had 3 relevant papers followed by the '*Agricultural Economics*', '*Economic Development and Cultural Change*' and '*Water Policy*' each with 2 relevant articles. When the total number of papers used in the SR was analysed based on their year of publication, the highest number is observed for the period 2003-2005 (Figure 3).

Figure 2 Number of relevant articles per journal or organization.

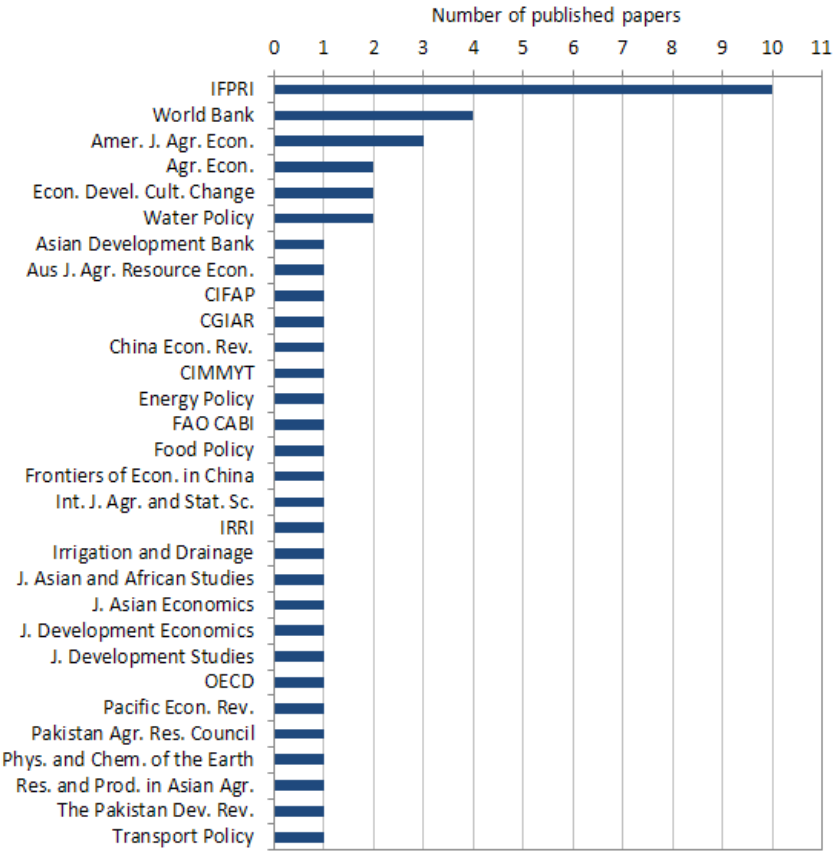
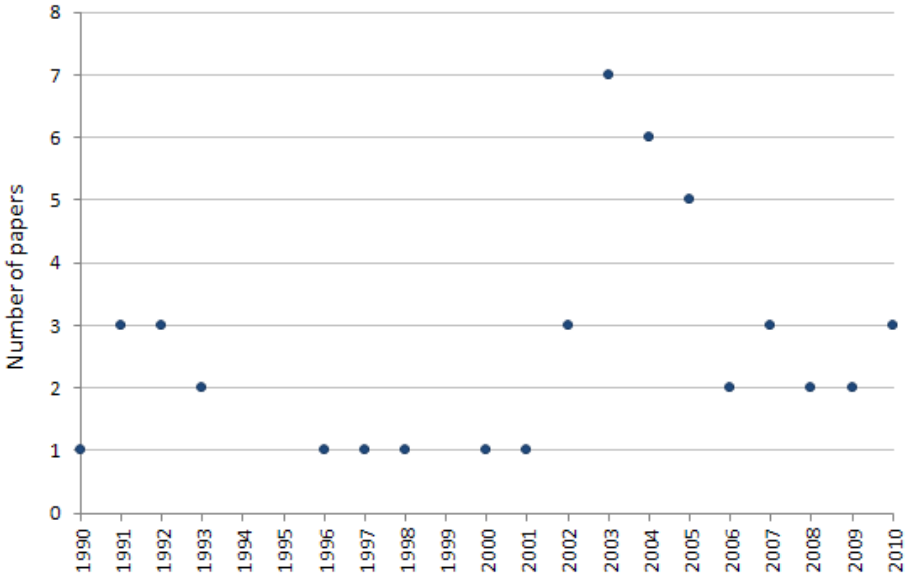
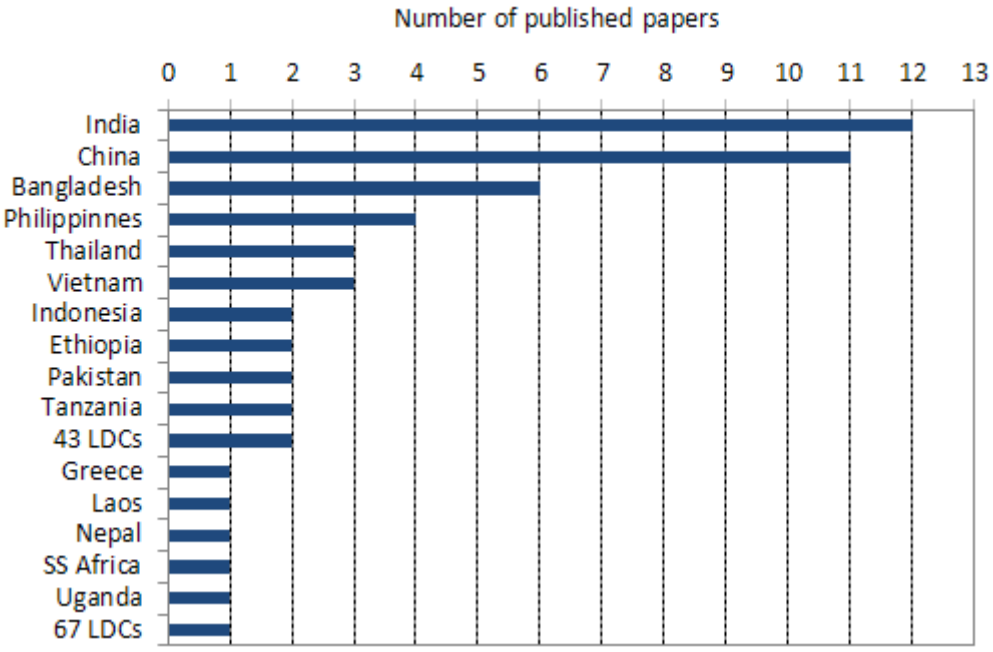


Figure 3 Number of peer review articles used in the SR, based on year of publication.



Some sources concentrated their research on a single country whilst others covered multiple countries. India and China have the largest number of studies tackling the impacts of infrastructure development on the rural community and agricultural productivity followed by Bangladesh and Philippines (Figure 4).

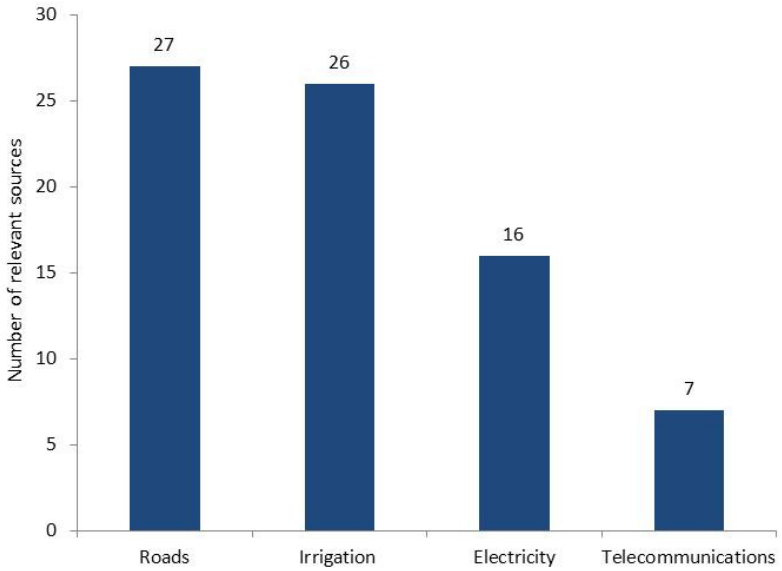
Figure 4 Number of relevant peer review articles published, by country.



From the final listing of screened articles, transport and irrigation were the infrastructural developments most studied, followed by electricity; telecommunications infrastructure investment was analysed the least (

Figure 5).

Figure 5 Number of relevant articles dealing with impact of different infrastructure type on agricultural productivity.



4.2 Narrative synthesis: road infrastructure investment impact

The interaction between road infrastructure and agricultural development is an indirect one in which road access improvements facilitates the movement of agricultural extension services, inputs and marketed surpluses. This facilitation role depends on the existence of a right of way along which motorised and non-motorised vehicles and transport services can operate. Ideally, the right of way should be engineered[1] to provide all-weather access but seasonal access before and after the main rains may be sufficient for moving bulky inputs and the harvesting and marketing of most crops[2]. In either case the road must be capable of being used by transport services that are affordable by the farming households producing a marketable surplus. The road must also be maintained so that its access benefits are sustained in support of agricultural investments like irrigation or the risks involved in shifting from subsistence to cash crop farming. Given this relationship, it is reasonable to expect that the impact of road infrastructure would bring about the following agricultural changes:

- The extension or intensification of the cultivable area;
- Increased number and range of crops being grown;
- Greater use of agricultural inputs and credit;
- Increased productivity and marketed surpluses;
- Greater use of external markets with a commensurate increase in prices and returns.

The scope and strength of the above changes will in turn be dependent on the agro-climatic, social and spatial characteristics of the area affected by the road improvements as well as the internal demand for foodstuffs and beyond this the global market in agricultural commodities.

The reviewed literature supports many of these linkages though the relationship is sometimes not particularly strong due to the existence of intervening factors defined as "effect modifiers" in Section 3.3. Similarly, the case studies consider a range of infrastructure interventions from the opening up of inaccessible areas with basic road infrastructure to the rehabilitation of existing roads. From an agricultural perspective, the first type of intervention is more radical than the second which tends to be incremental in its effect. Thus, Hine and Riverson's work in Ghana (1982) indicated that the improvement or rehabilitation of an existing road had a negligible impact on farm prices but the upgrading of a footpath to a road providing vehicle access had a "beneficial effect in the order of a hundred times" on farm prices as farmers and traders shifted from headloading to motorised vehicles to buy and sell their crops.

[1] The road way should be raised above any localised flooding and provide a free-draining, load-bearing riding surface for vehicles likely to use it as well as appropriate structures across any water channels along its length.

[2] Most seasonal crops are harvested and marketed after the rains and can be transported over small earthen roads or tracks. In contrast, crops such as tea that are marketed during the rainy season need all weather gravel or paved roads if they are to be transported to the market/processing plant in a timely fashion.

Work by Renkowa *et al* (2004) in Kenya confirms this "the absence of motorized transport [rather than access per se] is indicative of ….. economic isolation". Lebo and Schelling (2001) went on to express the importance of connection to the road network in terms of the cost of moving agricultural inputs and suggesting that this had a knock-on effect on farm household incomes. Data from 40 villages in the Andhra Pradesh Region of India were collected and their survey results are summarized in Table 6.

Table 4 Movement of farm inputs (km) and transport costs ($US/ton-km) for villages (Andhra Pradesh Region, India) connected and unconnected to all-weather access roads.

Avg. distance travelled (km) for:	**Connected**	**Unconnected**
Fertilizer	11.0	19.0
Seeds	11.0	19.0
Pesticides	9.0	16.0
Transport cost ($US/ton-km)		
Fertilizer by bullock cart	0.13	0.33
Seeds by bullock carts	0.10	0.26
Fertilizer by lorry	0.16	0.25
Seeds by lorry	0.08	0.11
Household income ($US/yr.)	700	275

Source: 1997 Survey Data in Lebo and Schelling (2001).

Similarly, a recent published impact study in Nicaragua (Goss, Gilroy Inc. and Orbicon 2010), confirms the role of year-round vehicle access in stimulating the shift from subsistence farming to the marketing of farm produce and perishable products like milk and vegetables. While Gibson and Roselle's and Jacoby show that the road network has a significant effect in reducing poverty in Papua New Guinea (2002) and Nepal (2000). Given these observations, the study identifies a number of specific findings that illustrate the above changes and these are highlighted below.

Bangladesh

In Bangladesh, investment in rural roads i.e. upgrading to create motorised vehicle access, was reported to have had a positive impact on agricultural development and rural poverty, with an average 5 to 7%, increase in rural household incomes. This came about through a lowering of transport and input costs which lead to higher agricultural production and greater returns as a result of higher output prices. This was largely an agricultural intensification process that also provided greater employment opportunities and higher agricultural wages for landless and functionally landless[3] labourers. It was concluded that these employment gains were proportionally higher

[3] Functionally landless households have insufficient land for their needs and rely on farm and non-farm employment opportunities to support their households.

for poor than non-poor households and hence the greater pro-poor impact of road development (Khandker, 2009).

Interestingly, in a later study of road density and access, Khandkar (2010) indicated that infrastructure development and credit expansion are not randomly distributed but heavily determined by exogenous local agroclimatic endowments across villages i.e. the agricultural areas with the most potential received the greatest investment. This probably reflects a transport planning bias which favours areas of strong and fast growing demand to meet its objectives of reducing transport costs. It is also common for agriculturally more productive areas to be more densely populated and richer and exert stronger "political pressure" than poorer areas.

China

In China, earlier work by Cook (1998) confirms that road access has helped promote greater agricultural intensification and suggests that this corresponds to a shift from subsistence grain production to the cultivation of a wide range of cash crops and animals presumably in response to the growing urban demand for foodstuffs. Later work refines this effect by focusing on agricultural GDP and output and linking this to the quality of road access. "Low-quality" earthen roads[4], which are invariably found in rural China, have GDP benefit–cost ratios that are four times greater than those for "high-quality" roads (Fan *et al*., 2004; Fan *et al*., 2008). Furthermore, there appears to be no statistically significant relationship between "high quality" roads and the Agricultural GDP. In contrast, "low-quality" roads not only have a significant relationship but can also generate some 1.6 yuan of agricultural GDP and more than 5 yuan of rural non-farm GDP[5] for every yuan invested (Fan *et al*., 2004). He goes on to argue that this agricultural trend means that "low-quality" roads lift more rural and urban poor above the poverty line per yuan invested than do high-grade roads (Fan *et al*., 2008). This recognition of the importance of "low quality" access confirms Lebo and Shelling's view that the provision of all-season basic motorized access is essential for agricultural development.

Fan *et al*. (2004d) compared these findings with a similar study in Uganda. Here he confirmed that low-grade access roads were shown to have a much larger impact on agriculture and hence poverty than high-grade roads which had been surfaced with "gravel or murram" or tarmac.

Fan went on to examine the spatial impact of his findings and concluded that investments in western China not only led to the greatest reductions in regional inequality but also greatly contributed to poverty reduction, albeit with lower economic returns (Fan *et al*., 2002). In contrast, the economic returns to road investment are highest in the eastern and central regions where the rural and urban economies are that much more advanced and better able to take advantage of the transport access and cost changes associated with road improvements (Fan *et al*., 2004, 2008). This suggests that rural road investment has stimulated profit margins for urban based transporters and traders and possibly meant cheaper food in the

[4] These are referred to as "low quality" access roads in contrast to "high quality" gravelled and paved feeder, secondary and trunk roads.

[5] Road investments can also stimulate the diversification of the rural economy by the sale of non-farm goods and crafts.

towns, as well as providing cheaper rural travel and higher producer prices in rural areas.

Ethiopia

In Ethiopia, Dercon *et al* (2009) report on a longitudinal study that focused on changes in access to roads and agricultural extension services from 1994 to 2004. They examined the relationship between household consumption of both own grown and purchased food and non-investment non-food items and four road dependent benefit channels: the costs of acquiring inputs; output prices; rainfall, household and price shocks; and entry into non-farm productive activities. Their conclusion was that access to good roads increased consumption growth by 16.3% and reduced poverty by 6.9%. This was a statistically significant relationship and reflected the importance of good roads making it easier for households to access local market towns that in turn are linked to larger urban centres.

This study's focus on more remote villages illustrates the radical changes that can be brought about by road construction opening up inaccessible areas to vehicle transport. These findings are supported by an assessment of the Ethiopia Rural Travel and Transport Pilot Project, which found evidence that changes in road access, as measured by travel time, were associated with increased agricultural production. Thus, the construction of the 37 kilometre Daleti – Bildigilu road, opened up Oda Bildigilu wereda to motorable traffic, thereby reducing travel times from 5-6 hours by foot and or donkey to 30 minutes for a small truck. This was followed by a six-fold increase in the production of sesame from an average 20 quintals (2,000 kg) per surveyed farmer to 120 quintals (12,000 kg) before and after road improvements. This increase involved the clearing and cultivation of new farmland rather than intensification of existing farms. In contrast, the construction of a 45 kilometre long road connecting the town of Adigrat to Atsbi Wenberta wereda resulted in an increase in farm gate prices for tomatoes and other vegetables and a commensurate intensification of their production and use of inputs. Importantly, these changes were associated with businessmen both delivering inputs and buying at the farm gate using trucks to transport fertiliser and produce to and from market centres. Farmers not only benefitted from increased production and prices but also reduced the time and cost spent marketing their crops. Household incomes were reported to have risen along with household travel and mobility. Other studies in selected woredas in the SNNP province show that access to irrigation and markers/roads helped improve agricultural productivity in smallholder agriculture and contributed to poverty reduction (Hanjra *et al.,* 2009b).

Thailand

In Thailand, investment in rural roads has encouraged farmers to shift from subsistence crops to much higher value crops including livestock with farmers also benefiting from increased competition among buyers and traders coming into the community (Cook, 2005). These changes were brought about by both travel cost and time reductions but it was noted that the resultant increased agricultural incomes benefitted both poor and non-poor alike and there was no noticeable pro-poor impact. Interestingly, the study also suggested that paving a road had a greater impact on household incomes than gravelling an earthen road. This may reflect the fact that the

majority of Thai settlements have good basic access to the road network and there is a dynamic non-farm economy that provides a variety of non-farm income opportunities.

Vietnam

Using national and provincial government expenditure data from 1993 to 2000, Fan et al. (2004a) undertook a generalized estimating equations (GEE) approach to model the agricultural production function and in doing so identify coefficients i.e. elasticities, for each sector's contribution to this function. The resultant analysis gives the coefficient for roads as 0.111. This indicates that for every 1% increase in road investment, agricultural production will increase by 0.111%. This is statistically significant and confirms the close relationship between the level of agricultural development and the availability of a road network in Vietnam. Road investment was reported to have the second largest agricultural growth impact after government investment in agricultural research. Further analysis indicated that this growth in agricultural productivity had an impact on poverty reduction i.e. every 1% increase in agricultural production saw 0.56% of the poor lifted above the poverty line. The study concluded that for every dong invested in road improvements resulted in 3.01 dong of increased agricultural production and every billion dong spend on roads lifted 132 poor people above the poverty line[6].

In Vietnam, investment in transport and road improvements has normally been conducive to rural economic development as it reduces transportation and transaction costs for producers (e.g. Canning, 1998; Fay and Yepes, 2003; Calderón and Servén, 2004). Depending on the commodity, agricultural production can be promoted by different infrastructures. For example, improving roads and irrigation facilities has been shown to strengthen the production efficiency of coffee and coco industries in Sub Saharan Africa (SSA) whilst water in rural areas is crucial for dairy production (Limi, 2007). Smoother and faster roads facilitate a shift to high-value perishable product production (Cook, 2005). Telecommunications infrastructure is important in support of branding agricultural and non-agricultural commodities.

India

Fan *et al*. (2000) undertook a similar GEE analysis to model the agricultural production and poverty reduction functions of national and state expenditure. It was concluded that government investment on Agricultural Research and Extension and Roads had far larger impacts on agricultural productivity and poverty reduction than any other sector. Investment in roads not only contributed significantly to agricultural growth, by lowering agricultural input prices[7] but also provided greater opportunities to gain non-farm employment and increase both farm and non-farm wages. There was also some evidence that agricultural productivity gains were associated with increased landlessness, but this was not a statistically significant association. The study concluded that the Indian government should give priority to increasing its spending on rural roads and agricultural research and extension.

[6] The regional scale of this analysis makes it difficult to isolate the urban and rural poverty reducing effects of road improvements and Mu and de Walle's work suggests that have rural roads had relatively little impact on rural poverty communities (2002 and 2007).

[7] Total Factor Productivity growth, derived from land, labour, fertilizer, tractor and buffalo inputs.

Finally, an analysis of data from 256 districts in India showed that investment in rural roads, electricity and irrigation infrastructure contributed to agricultural growth such that districts with better infrastructure achieved faster growth (Narayanamoorthy and Hanjra, 2006). Investments in rural roads alone were insufficient to spur productivity growth.

Table 5 Effects of irrigation infrastructure on agricultural productivity in developing countries.

Country	Year	Source	Ag. productivity/ output indicator	Infrastructure indicator	Effect †
43 LDCs	1980-1998	Fan and Rao (2003)	Ag. Output	Irrigation	0.245**
67 LDC	1961-1990	Craig et al. (1997)	Labour productivity (%)	Irrigated area	-0.293**
Bangladesh	1991-2001	Khandker (2009)	Laspreyers Agr. Output index	Irrigated area	2.07***
			Laspreyers Agr. Price index	Irrigated area	-0.067
			Labour wage	Irrigated area	0.85
			Agr. Labour days	Irrigated area	0.1482
China	1988-2003	Chen (2007)	Total factor productivity (rice)	Reservoir (Capacity/ sown area)	0.202**
			Total factor productivity (rice)	Irrigated area	0.297**
			Total factor productivity (wheat)	Reservoir (Capacity/ sown area)	0.018
			Total factor productivity (wheat)	Irrigated area	0.207**
			Total factor productivity (Bean)	Reservoir (Capacity/ sown area)	0.23**
			Total factor productivity (Bean)	Irrigated area	0.49***
			Total factor productivity (Maize)	Reservoir (Capacity/ sown area)	0.31***
			Total factor productivity (Maize)	Irrigated area	0.299**
	1997	Fan et al. (2002)	Ag.GDP	Irrigation	1.88
	2000	Fan et al.(2004c)	Ag.GDP	Irrigation	1.45
	1996	Fan and Zhang (2004)	Ag. Output	Irrigation	0.26
	2000	Huang (2005)	Ag. Output (yuan/capita)	Irrigated area	3082
	2001	Huang (2006)	Productivity (wheat)	Irrigation	0.177
			Productivity (Cotton)	Irrigation	0.284
			Productivity (Maize)	Irrigation	0.294
			Household crop revenue	Irrigation	0.761
			Household crop revenue (rich area)	Irrigation	1.328
			Household crop revenue (poor area)	Irrigation	0.439
			Ag. Output (yuan/ha)	Irrigated area (GW)	1587
			Ag. Output(yuan/ha)	Irrigated area (SW)	2617

† When no unit is available the effect represents the change in the dependent variable (output indicator) when the independent variable (infrastructure indicator) change by 1 unit (1% or by the unit mentioned in the table).

Country	Year	Source	Ag. productivity/ output indicator	Infrastructure indicator	Effects
Ethiopia	1900-2000	Block (2008)	Ag.GDP	Irrigation	3.13
			Ag.GDP	Inv. Irrigation & Roads	3.29
India	1960-1982	Binswanger (1993)	Fertiliser demand	Canal irrigation	0.059
	1970-1994	Fan et al. (2000)	Productivity	Irrigation	0.036
	1974-1994	Narayanamoorthy (2007)	Productivity of food grain (kg/ha)	GW/TRP (per '000 rural pop)	8.43***
			Productivity of food grain (kg/ha)	Irrigated area/TRP	0.36***
			Cropping intensity (%)	GW/TRP	0.22***
			Cropping intensity (%)	Irrigated area/TRP	0.09***
			Agr. Labour wage	GW/TRP	0.009**
			Agr. Labour wage	Irrigated area/TRP	0.003***
	1965-1995	Evenson and Gollin (2003)	Productivity (Rice Kg)	Irrigation (ha)	-0.1922
			Productivity (Wheat Kg)	Irrigation (ha)	0.316
			Productivity (Maize Kg)	Irrigation (ha)	0.287
			Productivity (Sorghum Kg)	Irrigation (ha)	0.314
			Productivity (Millet Kg/)	Irrigation (ha)	0.8452
			HYV adoption (Rice)	Irrigation	0.091
			HYV adoption (Wheat)	Irrigation	0.077
			HYV adoption (Maize)	Irrigation	0.057
			HYV adoption (Sorghum)	Irrigation	-0.002
			HYV adoption (Millet)	Irrigation	0.0013
	1994-1995	Saleth (2003)	Cropping intensity (%)	Irrigation	0.1711
			Land productivity (Rp/ha)	Irrigated area	0.5026
Philippines	1974-2000	Teruel (2005)	Cost of Agr. Production	Irrigation	-0.1253
			Demand for labour	Irrigation	-0.2328
			Intermediate input (fertilizers / seeds)	Irrigation	-0.5012
			Capital (machinery/animal labour)	Irrigation	0.6497

			Productivity growth	Irrigation	0.0031
Philippines	1961-1998	Mundlak et al.(2002)	Ag.GDP	Irrigation	2.21
Country	**Year**	**Source**	**Ag. productivity/ output indicator**	**Infrastructure indicator**	**Effect**
Indonesia	1971-1998	Mundlak et al.(2002)	Ag.GDP	Irrigation	0.583
Thailand	1971-1995	Mundlak et al.(2002)	Ag.GDP	Irrigation	0.103
	1977-2000	Fan et al. (2004b)	Ag. Output	Irrigation	0.71
Indonesia	1971-1998	Mundlak et al.(2002)	Ag.GDP	Irrigation	0.583
	1980-1998		Ag.GDP	Irrigation	0.463
Vietnam	1992-1993	Van de Walle (1996)	Ag. Output (Dongs)	Irrigated area ($100m^2$)	48571
			Ag. Output (Dongs-)	Non irrigated land ($100m^2$)	19994
			Ag. Output (Dongs-)	Irrigated area($100m^2$)	48226
			Ag. Output (Dongs)	Non irrigated land($100m^2$)	21876
	1993-2003	Fan et al. (2004a)	Ag. Output	Irrigation	0.42
			Poverty reduction (nb/ million Dongs)	Irrigation	12.93
India	1960-1982	Binswanger (1993)	Crop price (domestic)	Canal irrigation	0.033
			Crop price (International)	Canal irrigation	0.026
SS Africa	2004	Limi (2007)	Product price (Coffee/chocolate/cocoa)	Irrigation	-0.0127
			Product price (Milk/butter/cheese)	Water access	-0.02
	2001-2005		Ag.GDP	Water access	-0.009
Tanzania	2003	Mwakalila (2006)	yield growth	Irrigation	1
			Gross margin (tsh)	Irrigation area (ha)	1.98
			Return to labour (tsh/man day)	Irrigation area (ha)	4.83

Note: Asterisks indicate variables of which coefficients are significant at the 10% (*), 5% (**), and 1% (***) levels. Blanks shown where no statistical significance is reported – note this is different from N/S – not significant.

Table 6 Effects of irrigation infrastructure on poverty reduction in developing countries.

Country	Year	Source	Ag. productivity/ output indicator	Infrastructure indicator	Effects
China	1997	Fan et al.(2002)	Poverty reduction (nb)	Irrigation inv. (10000 yuan)	1.33
	2000	Fan et al. (2004c)	Poverty reduction (nb)	Irrigation inv. (10000 yuan)	2.31
	2001	Huang (2006)	Household crop revenue	Irrigation	0.761
			Household crop revenue (rich area)	Irrigation	1.328
			Household crop revenue (poor area)	Irrigation	0.439
India	1970-1994	Bhattarai (2003)	Poverty reduction (HCR)	Irrigation	-0.37
			Poverty reduction (HCR)	Irrigated area	-0.25
			Poverty reduction (HCR)	% Groundwater area	-0.25
			Poverty reduction (HCR)	% Surface water area	-0.27
	1970-1994	Fan et al.(2000)	Poverty reduction (nb)	Irrigation inv.(million rupees)	9.7
	1974-1994	Narayanamoorthy (2007)	Poverty reduction	GW irrigated area/capita	-250
			Poverty reduction	GW irrigated area/capita	-210
	1973-1974	Pandya (2010)	Rural consumption (Rupees/person)	Irrigated area	0.12
Philippines	1988	Balisacan (2002)	Poverty reduction	Irrigated area	9.301
Thailand	1977-2000	Fan et al. (2004b)	Poverty reduction (nb)	Irrigation.inv (million Bhat)	7.69
Vietnam	1993-2003	Fan et al. (2004a)	Poverty reduction (nb)	Irrigation inv (million Dongs)	12.93

Table 7 Effect of road infrastructure on agricultural productivity in developing countries.

Country	Year	Source	Ag. productivity/output indicator	Infrastructure indicator	Effect
Bangladesh	2000	Khandker (2009)	Transport cost	Road development	-0.363
	2000		Fertiliser price (taka/kg)		-0.045
	2000		Daily Agr.Wage		0.27
	2000		Fertiliser price (taka/kg)		-0.047
	2000		Daily Agr.Wage		0.019
	2000		Transport cost		-0.38
	1991-2001	Khandker (2010)	Laspreyres Agr. Price index	Road access	-0.011
			Agr.Wage		1.07
			Agr. Labour days		0.9
			Laspreyres Agr. Output index	Road density	-0.006
China	1998	Cook (2005)	Change in grain area (%)	Road access	-27.72
			Change in cash crop area (%)		126.24
			Change in vegetable area (%)		36.71
			Change in pig number (%)		47.93
			Changes in sheep number (%)		17.51
			Changes in goat number (%)		-8.08
			Changes in chicken number (%)		303.5
	1997	Fan et al. (2002)	Ag.GDP	Road development	2.12
	1982-1999	Fan and Chang-Kang (2004)	Ag.GDP	Road investment (low quality)	1.48
	2000		Ag.GDP	Road development	1.69
	2001	Fan and Chan-Kang (2008)	Ag.GDP	Road investment (low quality)	2.55
	1996	Fan and Zhang (2004)	Ag.output	Road development	0.032
	1982-1999	Fan (2005)	Ag.GDP	+1km of high quality road	N.S.
			Ag.GDP	+1km of low quality road	0.285
Ethiopia	1900-2000	Block (2008)	Ag.GDP	Inv. In irrigation and roads	3.29

Country	Year	Source	Ag. productivity/output indicator	Infrastructure indicator	Effect
India	1960-1982	Binswanger (1993)	Fertiliser demand	Road development	0.224
			Crop price (International)	Road development	0.201
			Crop price (Domestic)	Road development	0.215
	1970-1994	Fan et al (2000)	Total factor productivity	Road development	0.057
	1982-1984	Wanmali (1992)	Fertiliser price (%)	Road development	-4.3
			Revenue from market	Road development	-0.62
Indonesia	1971-1998	Mundlak et al (2002)	Ag.GDP	Road development	0.084
Philippines	1974-2000	Teruel (2005)	Cost of Agr. production	Road investment	-0.7115
			Demand for labour	Road investment	-1.1889
			Intermediate input (fertilizers/seeds)	Road investment	-1.0518
			Capital (machinery/animal labour)	Road investment	1.806
			Ag. production	Road investment	0.0151
SS Africa	2004	Limi (2007)	Product price (Coffee/chocolate/cocoa)	Road density	-0.193
			Product price (Milk/butter/cheese)	Road density	0.035
Thailand	1971-1995	Mundlak et al (2002)	Ag.GDP	Road development	0.081
	1977-2000	Fan et al (2004)	Ag.output (Bhat)	Road development	0.86
Vietnam	1993-2003	Fan et al (2004)	Returns Ag. Production	Road development	3.01
43 LDCs	1980-1998	Fan and Rao (2003)	Ag. Production	Road density	0.177
67 LDC	1961-1990	Craig et al (1997)	Labour productivity	Road density	0.012

Table 8 Marginal returns from investment in transport.

Country	Year	Source	Ag. Productivity/ output indicator	Infrastructure indicator	Effects
Bangladesh	2000	Khandker (2009)	Transport cost	Road development	-0.363
			Laspreyres price index	Road development	0.05
			Laspreyres quantity index	Road development	0.386
			Laspreyres price index	Road development	0.035
			Laspreyres quantity index	Road development	0.304
	1991-2001	Khandker (2010)	Laspreyres agr. price index	Road access	-0.011
			Transport cost	Road access	1.38
China	1996-2001	Cook (2005)	Total GDP	Railway construction	10 - 21
	1997	Fan et al. (2002)	Rural GDP	Road development	8.83
	1982-1999	Fan and Chang-Kang (2004)	Total GDP	Road investment (low quality)	5.99
			Total GDP	Road investment (high quality)	1.55
			Return in rural non-farm GDP	Road investment (low quality)	5.34
			Return in rural non-farm GDP	Road investment (high quality)	0.65
			Rural GDP	Road development	4.88
			Marginal returns to Poverty reduction	Road development	6.57
	2001	Fan and Chan-Kang (2008)	Total GDP	Road investment (low quality)	8.66
			Rural GDP	Road investment (low quality)	7.59
			Total GDP	Road investment (high quality)	2.34
			Rural GDP	Road investment (high quality)	1.04
	1982-1999	Fan (2005)	Total GDP	+1km of high quality road	1.73
			Rural GDP	+1km of high quality road	0.729
			Total GDP	+1km of low quality road	1.158
			Rural GDP	+1km of low quality road	1.032
Ethiopia	1994	Dercon (2009)	Consumption growth (%)	Road access (all weather)	16.3
India	1960-1982	Binswanger (1993)	Crop price (domestic)	Road development	0.215
	1997-2002	Cook (2005)	Consumption growth (%)	Road development	-7.9 - 24.8
	1970-1994	Fan et al.(2000)	Rural GDP	Road development	5.31
	1973-1974	Pandya (2010)	Rural consumption (Rs/person)	Road density (km/1000km^2)	0.1
Thailand		Cook (2005)	Perceived consumption growth (%)	Road development	81.9

Country	Year	Source	Ag. Productivity/ output indicator	Infrastructure indicator	Effects
Tanzania	2000-2001	Fan et al. (2005)	Rural GDP	Road development	9.13
			Poverty Reduction (nb)	Road inv. (million shilligs)	26.53
Uganda	1992-1999	Fan et al. (2004d)	Total GDP (Shelling)	Feeder road	7.16
SS Africa	2001-2005	Limi (2007)	Ag. GDP	Road density	-0.009**
			Ag.GDP	Share of paved road	0.003

Table 9 Effects of telecommunication infrastructure on agricultural productivity in developing countries.

Country	Year	Source	Ag. productivity/ output indicator	Infrastructure indicator	Effects
Bangladesh	1998	Bayes,A. (2001)	Diesel supply	Telephone	Stable
			Fertilizer supply	Telephone	Regular
			Poultry mortality rate	Telephone	Lower
			Chicken/duck prices	Telephone	Higher
			Chick feeds prices	Telephone	Lower
China	1997	Fan*et al.* (2002)	Ag.GDP	Telephone	1.91
			Poverty reduction	Telephone	2.21
			Poverty reduction (nb/10,000 yuans)	Telephone	2.21
			Rural GDP	Telephone	6.98
	2000	Fan*et al.* (2004c)	Ag.GDP	Telephone	1.63
			Poverty reduction	Telephone	6.17
			Rural GDP	Telephone	2.59
			Rural GDP	Telephone	4.22
	1996	Fan and Zhang(2004)	Agriculture output	Telephone	0.056
			Nonfarm output	Telephone	0.119
Philippines	1974-2000	Teruel (2005)	Productivity growth	Technology	0.0181
SS Africa	2004	Limi (2007)	Product price (Coffee/chocolate/cocoa)	Rural teledensity	0.483
			Product price (Milk/butter/cheese)	Rural teledensity	-0.505
	2001-2005		Ag. GDP	Teledensity	-0.0009
Vietnam	1993-2003	Fan et al. (2004a)	Ag. production	Telephone	N.S.
			Poverty reduction	Telephone	N.S.

4.3 Narrative synthesis: electricity infrastructure investment impact

A summary of the reported results on the impacts of electricity investment on agricultural productivity and poverty reduction, are given in Table 10 and Table 11, respectively.

Most of the individual studies reviewed could not be compared directly because the magnitude of the effects of infrastructure investment varies between countries and is reported for different time periods. The endogeneity control is also important as the effects of infrastructure tend to be lower when endogeneity is taken into consideration (Pinstrup-Andersen and Shimokaya, 2006).

Among all the infrastructural investments, electricity had the least contribution to agricultural productivity in the Philippines (Teruel, 2005). This is consistent with an assessment by the World Bank (2002) showing that rural electrification and development in the Philippines appears to have had no effect on agricultural output or income.

Evenson and Quizon (1991) argue that a 'reverse causality' makes rural electrification respond to farm productivity levels. In Bangladesh, Khandker (2010) has found that rural electrification has led to higher agricultural prices but the positive effect of electrification on agricultural productivity was weak. However, investment in electricity does indirectly have a strong impact on agricultural growth, and on the welfare of the rural population (Mundlak *et al*., 2002). Greater electrification can raise productivity in agriculture as well as the quality or composition of agricultural output through greater investments in fixed capital such as pumps, tractors and farm machinery. In India, for example, the impact of electrification on investment in fixed capital (notably pumps) was significant and contributed to an increase of 28% in investment levels (Binswanger *et al*., 1993). Via these investments coupled with fertiliser demand (≈5% increase) electrification has increased agricultural output over a decade by around 2%.

The electricity impact can vary from commodity to commodity and from one crop to another based on its electricity requirement. For example, a modern intensive system of "factory farming" requires various inputs and agricultural machinery and hence production efficiency would be affected by the lack of or unreliable supply of electricity. For example, Limi (2007) showed that better quality roads and electricity infrastructure can significantly reduce the costs of beef production and export.

The geographical location of the crop is also important. For example, in China, maize is planted in the western regions because of the physical geography and local climate. However the west is also the poorest area in China, and has a shortage of hydroelectricity and therefore electricity investment in these areas might have a larger impact (Chen, 2007).

Although electricity investment in China showed low returns to both agricultural and non-agricultural GDP, its poverty reduction impact is significant (Fan *et al.*, 2007 and Fan *et al.*, 2004c). This is because access to electricity is essential to the expansion of non-farm employment (Fan and Zhang, 2004).

Results from low-income countries often show higher returns to road investments than telecommunications and electricity, but not in the case of Thailand, where investment in electricity was shown to have the highest return. Thailand has invested heavily in rural roads and a dense road network has been built, suggesting that additional

investment may yield diminishing returns (Fan *et al.*, 2004b). The Thai government expenditure on rural electricity has had the largest impact on poverty reduction. The effects of electricity, roads, and education come from growth in agricultural labour productivity as well as improvements in rural nonfarm employment and rural-urban migration rather than from increasing agricultural productivity (Fan *et al.*, 2004b).

Additional investments in the Northeast region of Thailand contributed more to reducing poverty than investments in other regions. This is because most of the poor are now concentrated in the Northeast and this region has suffered most from under investment in the past.

Table 10 Effects of electricity infrastructure investment on agricultural productivity in developing countries.

Country	Year	Source	Ag. productivity/ output indicator	Infrastructure indicator	Units	Effect	Sig
Bangladesh	1991-2001	Khandker (2010)	Ag.Output	households with elect. in village	%	0.151	
			Agr.Price	households with elect. in village	%	0.057	***
			Agr. Transport costs	households with elect. in village	%	0.43	***
			Agr. Wage	households with elect. in village	%	1.07	
			Agr.Labour	households with elect. in village	%	0.95	
China	1988-2003	Chen (2007)	Total factor productivity (Rice)	Electricity consumption/capita		-0.52	
			Total factor productivity (Wheat)	Electricity consumption/capita		0.455	
			Total factor productivity (Bean)	Electricity consumption/capita		-0.132	**
			Total factor productivity (Maize)	Electricity consumption/capita		-0.005	
	1997	Fan *et al.* (2002)	Ag.GDP	Electricity		0.54	
	2000	Fan *et al.*(2004c)	Ag.GDP	Electricity		0.82	
	1996	Fan and Zhang (2004)	Ag.Output	Electricity/Machinery		0.115	**
India	1960-1982	Binswanger (1993)	Fertiliser demand	Electricity		0.085	*
			Crop Price (International)	Electricity		0.028	*
			Crop Price (Domestic)	Electricity		0.031	*
	1970-1994	Fan*et al.* (2000)	Total factor productivity	Electricity		0.004	
Philippines	1974-2000	Teruel (2005)	Cost of Agr. Production	Electricity		-0.0191	
			Agr.Labour	Electricity		-0.0991	
			Intermediate input (fertilizers / seeds)	Electricity		-0.2163	
			Capital (machinery/animal labour)	Electricity		0.4999	
			Total factor productivity	Electricity		0.0018	
SS Africa	2004	Limi (2007)	Product price (coffee/chocolate/cocoa)	Electricity consumption		0.009	
			Product price (milk/butter/cheese)	Electricity consumption		0.009	
			Ag. power consumption	Electricity consumption		-0.008	
Thailand	1971-1995	Mundlak *et al.*(2002)	Ag.GDP	Electricity		0.045	*
	1977-2000	Fan *et al.*(2004b)	Ag.Output	Electricity		4.89	

Note: Asterisks indicate variables of which coefficients are significant at the 10% (*), 5% (**), and 1% (***) levels. Blanks shown where no statistical significance is reported – note this is different from N/S – not significant.

Table 11 Effects of electricity infrastructure investment on poverty reduction in developing countries.

Country	Year	Source	Ag. productivity/ output indicator	Infrastructure indicator	Units	Effect	Sig
China	1998	Cook (2005)	Poverty reduction	Electricity		8.33	
			Poverty reduction	Roads and electricity		6.29	
	1997	Fan *et al.*(2002)	Poverty reduction(nb)	Electricity inv. (10,000 yuans)		2.27	
			Poverty reduction (nb)	Electricity inv. (10,000 yuans)		2.27	
	2000	Fan *et al.* (2004c)	Poverty reduction (nb)	Electricity inv. (1 million yuan)		4.85	
	1990	Yang (2003)	Poverty reduction	Electricity inv. (1 million yuan)		-85- -1960	
			Income of rural/capita (yuan)	Electricity inv. (million yuan)		0.17 - 1.85	
India	1970-1994	Fan*et al.*(2000)	Poverty reduction (nb)	Electricity inv. (million Rupees)		3.8	
Philippines	1988-1997	Balisacan (2002)	Poverty reduction	Electricity		0.308	
Tanzania	2000-2001	Fan *et al.* (2005)	Poverty reduction	Electricity		141962	
Thailand	1977-2000	Fan *et al.*(2004b)	Poverty reduction (nb)	Electricity inv. (million Bhat)		276.07	
Vietnam	1993-2003	Fan *et al.*(2004a)	Poverty reduction	Electricity			N.S.

Table 12 Marginal returns from investment in electricity infrastructure.

Country	Year	Source	Ag. productivity/ output indicator	Infrastructure indicator	Effects
China	1997	Fan*et al.* (2002)	Ag.GDP	Electricity	0.54
			Rural GDP	Electricity	1.26
	2000	Fan*et al.* (2004c)	Ag.GDP	Electricity	0.82
			Rural non-farm GDP	Electricity	2.07
			Rural GDP	Electricity	2.89
	1990	Yang (2003)	Income of rural/capita (yuan)	Electricity inv. (million yuan)	0.17 - 1.85
India	1970-1994	Fan*et al.* (2000)	Marginal returns to rural investment	Electricity	0.26
			Total factor productivity	Electricity	0.004
SS Africa	2001-2005	Limi (2007)	Ag.GDP	Electricity consumption	0.00004
Thailand		Cook (2005)	Consumption	Electricity connection	87.3
Thailand	1971-1995	Mundlak *et al.* (2002)	Ag.GDP	Electricity	0.045

4.4 Narrative synthesis: irrigation infrastructure investment impact

Investment in irrigation can potentially generate more reliable and higher productivity (yields) in agriculture, thereby raising agricultural incomes (Hussain and Hanjra, 2003; Hussain and Hanjra, 2004). This, in turn, can lead to greater spending in the local economy and hence higher non-farm incomes (Khandker, 2010). As with any infrastructural investment, irrigation not only yields high returns to agricultural production, but it can also have a direct impact on poverty reduction. This is because most of the poor in the 43 least developed countries reside in rural areas and their main source of livelihood is agriculture (Fan and Rao, 2003). Poor urbanize faster. Investments in irrigation also helped reduce disparity among rural and urban areas and thus reduced urbanization by providing better infrastructure and services in selected rural settings (Narayanamoorthy and Hanjra, 2010).

A summary of the SR outputs relating to irrigation infrastructure impacts on agricultural productivity and poverty reduction is given in Table 5 and Table 6. Specific findings for selected countries from the SR are summarised below.

China

Government spending on agricultural production enhancing investments such as irrigation, education and infrastructure all contributed to growth in Chinese agricultural productivity and helped to reduce regional inequality and rural poverty. But variations in their marginal effects on productivity were large, particularly among the different types of spending as well as across different regions. China has invested heavily in irrigation in the past; further irrigation investment will thus have only modest impacts on growth in agricultural production and even less impact on rural poverty reduction (Fan et al., 2002; Fan et al., 2004c).

Regional variation in the marginal returns to government spending in terms of both GDP growth and poverty reduction is large. The low agricultural productivity of the Western regions of China is explained by its lower level of rural infrastructure, education and technology (Fan and Zhang, 2004). Therefore investment in infrastructure in this region will reduce the differences in productivity compared against other regions in the country. Irrigation has had a significant positive effect on total factor productivity of wheat and rice but has been insignificant for bean (Chen, 2007). The irrigation impact on crop revenue is estimated to be 132% in the richer areas and 43% in the poorer areas.

Irrigation has had a significant positive effect on crop revenue but the magnitude of impact differs depending on the water source and between richer and poorer areas (Huang, 2006). The percentage increases in crop revenue of fields irrigated by surface water are much higher in rich areas compared to poorer areas (Huang, 2006). This is probably caused by scarce water resources and/or poor water distribution efficiency in the poorer areas. Huang (2005) found a strong and significant relation between irrigation and cropping income but the relation with off-farm income was not significant.

Therefore, investment in irrigation would increase the total income of poor households and hence lead to poverty reduction. Whilst irrigation can help to raise growth and reduce poverty and inequality, it should not necessarily be the government's primary tool for development in all regions. Cost benefit analysis is also

necessary to justify investment in new irrigation projects (Huang, 2005). With such a high proportion of the existing cultivated area already under irrigation command, the cost for installing new irrigation systems is likely to be high in much of China.

India

Binswanger (1996), Saleth (2003) and Fan et al. (2000) found that the rate of return to new irrigation investment in India has been declining over time. The initial contribution of irrigation was through expansion of cultivation, more intensive use of agricultural land and cropping pattern changes (employment enhancement variables) but when the limits for initial contributions were reached and the interactive effects of irrigation and technologies become consolidated, the contribution of irrigation occurred through improvement in land and labour productivity (termed productivity enhancement variables) (Saleth, 2003).

Indeed, increased investment in irrigation played a major role in production growth during the Green Revolution. Without these investments, the returns to investments in roads and research would have been much smaller (Fan et al., 2000) and therefore, any measure of irrigation potential must include both the 'developed' as well as 'yet to be developed' potential (Binswanger, 1996).

In terms of agricultural productivity, Fan et al. (2000) identified irrigation investment to have the third largest impact on growth in agricultural productivity after roads and agricultural research. Evenson and Gollin (2003) found that irrigation expansion has been primarily driven by modern and higher yielding varieties and that irrigation development tends to reduce the market share of rice and wheat. Fan et al. (2000) reported that the impact of irrigation on rural poverty is smaller than its impact on agricultural productivity.

Narayanamoorthy (2007) showed a significant inverse relationship between the availability of groundwater for irrigation and the percentage of rural poverty in India, for five contrasting time periods between 1973 and 1994. Hence recommendations for groundwater abstraction for irrigation and rural electrification development together with the institutional credit support were recommended as effective measures to reduce rural poverty.

The Philippines

In the Philippines, agricultural productivity between 1974 and 2000 was reported to have stagnated as public expenditure shifted from irrigation research and road investment to agrarian reform and environmental and resources management (Teruel, 2005). As in China and India, previous major investments in irrigation reduced returns from new irrigation projects (Fan et al., 2004b). Spending therefore shifted to improve the efficiency of existing irrigation systems through reforming pricing incentives and modernising the institutions responsible for managing the irrigation water.

Vietnam

In Vietnam, irrigation investment was reported to have had a small impact on agricultural growth but a large impact on poverty reduction (Fan et al., 2004a). The greatest impact occurred in the poorest regions. Van de Wall (1996) reported that the

greatest impact was in the Northern Uplands and the North Coast whilst Fan et al. (2004a) identified the North Central and Highlands regions for poverty reduction; the Southeast and highlands were targeted for agricultural growth.

Ethiopia

Block (2008) found that irrigation investment boosted agricultural GDP in Ethiopia and an irrigation investment strategy tended to fare slightly better than road investments. This is mainly due to the fact that additional irrigation reduces the negative impact of drought on production and farm income.

Tanzania

In Tanzania, irrigation investment was shown to support farmers in growing and harvesting two paddy seasons per year, which increased small farmers' productivity and income, and alleviated rural poverty (Mwakalila, 2006).

Sub Saharan Africa

Agriculture is particularly important in Sub Saharan Africa where 12 out of 36 countries have agriculture contributing to more than 30% of their total GDP and more than 10% of their total exports. A study conducted by Iimi and Smith (2007) found that irrigation following the road facilities in SS Africa could strengthen production in the coffee and cocoa industries and it is impact is variable depending on the commodity and on the climatic conditions.

4.5 Quantitative analysis – by impact indicator

Ideally, all the articles included in the systematic review would have used the same measure of impact in response to the various interventions. This would then allow a full quantitative meta-analysis of the results. However, as discussed in the inclusion criteria, this study has interpreted "agricultural productivity" much wider than simply yield per hectare. Therefore, in the studies reviewed a wide range of indicators were identified and have been used as direct or proxy indicators of agricultural productivity.

Although there were 307 "observations" of the impact of investment in rural infrastructure on agricultural productivity, in reality a wide range of indicators were used. These were therefore categorised into nine main classes:

1. **Agricultural productivity**: Measures of crop yield and output per unit area.
2. **Consumption**: Measures of rural consumption and expenditure.
3. **GDP**: Measures of changes in total or rural GDP.
4. **Income**: Measures of rural income, crop revenues and gross margins.
5. **Inputs**: Measures prices, demand, use and supply of agricultural inputs including seeds, fertilisers, fuel, labour and high yielding varieties (HYVs).

6. **Labour**: Measures of rural employment and wages.
7. **Poverty**: Measures of the number of people in poverty.
8. **Prices**: Measures of process of agricultural outputs.
9. **Production**: Measures of the quantity of production of crops and livestock.

Table 13 Number of observations in each indicator category.

Indicator	Roads	Electricity	Irrigation	Telecom	Mixed	Total
Agric productivity	2	2	13		7	24
Consumption	6	7	1			14
GDP	33	5	7	5	3	53
Income	4	3	18	1	2	28
Inputs	11	10	21	3	8	53
Labour	5	2	4		1	12
Poverty	32	11	15	3	3	64
Prices	9	6	5	3	3	26
Production	12	5	12	3	1	33
Total	**114**	**51**	**96**	**18**	**28**	**307**

However, even within an impact category, different quantitative measures have been used. For example, in the literature that reported the impact of investment in roads on poverty (32 observations), seven different indicators were used, including; change in per capita expenditure, marginal returns to rural investment, poverty, reduction in number in poverty (total), reduction in number in poverty (rural), reduction in number in poverty (urban), and variation in poverty. In all, we identified over 100 unique quantitative indicators of the impact of investment in the four infrastructure types.

The same indicator is most of the time reported in different units that cannot be compared or normalized in order to perform a consistent comparison. As an example, irrigation impact on agricultural output could be as $ revenue per $ invested or revenue in local currency per irrigated area or Agricultural GDP per % change in irrigated area. This discrepancy in units has reduced the sample sizes of comparable observations (e.g. only two studies[8] reported the effect of investment in roads on agricultural productivity in the same units) to carry out a quantitative meta-analysis of the impact of the impact of investments in infrastructure on agricultural productivity.

Therefore, each impact indicator was categorised into "positive" or "negative" impact on agricultural productivity. For example, crop yield would be positive, whereas fertiliser price would be negative. All reported effects of negative indicators were multiplied by -1 to convert them to positive effects (e.g. fertiliser price would be converted to reduction in fertiliser price). Each reported effect was then identified as a positive or negative effect on agricultural productivity. 'No effect', or 'non-significant effects' were classed as neutral. The number of reported positive, neutral or negative effects was then compared for each infrastructure type and impact category. Although this does not allow a quantitative conclusion to be drawn, it identifies the degree of consistency of response among infrastructural investments. The overall impacts of

[8] Fan, Hazell and Thorat (2000); Teruel, (2005)

infrastructural development (i.e. roads, electricity, telecommunications and irrigation) on agricultural productivity have been analysed by aggregating all the individual data from each reported study.

A summary of the number of observations for each infrastructure investment, for each of the nine specific impact indicators is given in Table 14.

Table 14 Number of reported observations in each impact indicator category.

1. **Agricultural productivity**

	Trans	**Elect**	**Irrig**	**Telecom**	**Mixed**	**Total**
Cropping intensity	-	-	3	-	-	3
Growth rate	-	-	-	-	6	6
Land productivity	-	-	1	-	-	1
Maize yield	-	-	1	-	-	1
Millet yield	-	-	1	-	-	1
Productivity of food grain	-	-	2	-	-	2
Rice yield	-	-	1	-	-	1
Sorghum yield	-	-	1	-	-	1
Total factor productivity	2	2	2	-	1	7
Wheat yield	-	-	1	-	-	1

2. Consumption

	Trans	**Elect**	**Irrig**	**Telecom**	**Mixed**	**Total**
% expenditure	3	6				9
% growth	1					1
% per capita	1	1				2
Rural consumption	1		1			2

3. GDP

	Trans	Elect	Irrig	Telecom	Mixed	Total
GDP (agricultural)	1		1		1	3
GDP (non-agricultural)	1		1		1	3
GDP (total)	2		1		1	4
Marginal returns to expenditure (agricultural)	10	2	2	2		16
Marginal returns to expenditure (non-farm)	5	1		1		7
Marginal returns to expenditure (rural non-farm)	4					4
Marginal returns to expenditure (rural)	4	2	2	2		10
Marginal returns to expenditure (total)	6					6

4. Income

	Trans	Elect	Irrig	Telecom	Mixed	Total
Cotton crop revenue			1			1
Crop revenue			8		1	9
Gross margin			1			1
Income of rural area		1				1
Livestock and fisheries income					1	1
Maize crop revenue			1			1
Marginal effect on net crop income			2			2
Marginal return for rural investment	2	1	1			4
Peanut crop revenue			1			1
Returns to agricultural Production	1	1	1	1		4
Revenue from market	1					1
Rice crop revenue			1			1
Wheat crop revenue			1			1

5. Labour

	Trans	Elect	Irrig	Telecom	Mixed	Total
Agricultural wage	3	1	1			5
Demand for labour	1	1	1			3
Labour productivity	1		1			2
Non agric. labour					1	1
Return to labour			1			1

6. Inputs

	Trans	Elect	Irrig	Telecom	Mixed	Total
Agricultural labour	1	1	1			3
Agric transport costs	1	1	1			3
Capital (machinery / animal labour)	1	1	1			3
Chick feed prices				1		1
Cost agric production	1	1	1			3
Daily transport cost	2					2
Diesel supply				1		1
Fertiliser demand	1	1	1			3
Fertiliser price	3				1	4
Fertilizer supply				1		1
Fertilizers consumption					1	1
Intermediate input (fertilizer / seed)	1	1	1			3
Irrigation					1	1
Labour			2		1	3
Labour					1	1
Labour cost					1	1
Maize HYV adoption			1			1
Millet HYV adoption			1			1
Rice HYV adoption			1			1
Sorghum HYV adoption			1			1
Total factor productivity (bean)		1	2			3
Total factor productivity (maize)		1	2			3
Total factor productivity (rice)		1	2			3
Total factor productivity (wheat)		1	2			3
Total labour					1	1
Use of HYV					1	1
Wheat HYV adoption			1			1

7. Prices

	Trans	Elect	Irrig	Telecom	Mixed	Total
Chicken/duck prices				1		1
Crop price (domestic)	1	1	1			3
Crop price (international)	1	1	1			3
Laspeyres agr. price index	1	1	1			3
Laspeyres price index	4					4
Product price (coffee/choc/cocoa)	1	1	1	1		4
Product price (milk/butter/cheese)	1	2	1	1		5
Rice price					3	3

8. Poverty

	Trans	Elect	Irrig	Telecom	Mixed	Total
Capita expenditure	4					4
Marginal returns to rural investment	2	1	1			4
Poverty	1	1	1			3
Poverty level (head count ratio)			3			3
Reduction in number in poverty	12	9	7	2	2	32
Reduction in number in poverty (Rural)	8					8
Reduction in number in poverty (Urban)	4					4
Rural poverty			1			1
Rural poverty			1		1	2
Variation in poverty	1		1			2
(blank)				1		1

9. Production

	Trans	Elect	Irrig	Telecom	Mixed	Total
Agricultural Production Index	3		3			6
Agriculture output	1	1	1	1		4
Change grain area	1					1
Change in cashcrop area	1					1
Change Vegetable area	1					1
Cotton yield			1			1
Laspeyres agr. output index		2	1			3
Maize yield			1			1
No. chicken	1					1
No. goats	1					1
No. pigs	1					1
No. sheep	1					1
Non-farm output		1		1		2
Poultry Mortality rate				1		1
Production function (model A)			1			1
Production function (model B)			1			1
Production growth	1	1	1			3
Rice output			1		1	2
Wheat yield			1			1

Since a wide range of different measures were found in the literature for assessing the impacts of infrastructure development on agricultural productivity, it was therefore necessary to define the preferred direction of impact (either positive or negative) in order to then aggregate the data and undertake some quantitative analysis (

Table 15).

Table 15 Assumed direction of impact for each impact indicator.

Agricultural productivity	Negative	Positive
Cropping intensity		✓
Growth rate		✓
Land productivity		✓
Maize yield		✓
Millet yield		✓
Productivity of food grain		✓
Rice yield		✓
Sorghum yield		✓
Total factor productivity		✓
Wheat yield		✓

Consumption	Negative	Positive
% Expenditure		✓
% growth		✓
% per capita		✓
Rural consumption		✓

GDP	Negative	Positive
GDP (agricultural)		✓
GDP (non-agricultural)		✓
GDP (total)		✓
Marginal returns to expenditure (agricultural)		✓
Marginal returns to expenditure (non-farm)		✓
Marginal returns to expenditure (rural non-farm)		✓
Marginal returns to expenditure (rural)		✓
Marginal returns to expenditure (total)		✓

Income	Negative	Positive
Cotton crop revenue		✓
Crop revenue		✓
Gross margin		✓
Income of rural area		✓
Livestock and fisheries income		✓
Maize crop revenue		✓
Marginal effect on net crop income		✓
Marginal return for rural investment		✓
Peanut crop revenue		✓
Returns to agricultural production		✓
Revenue from market		✓
Rice crop revenue		✓
Wheat crop revenue		✓

Inputs	Negative	Positive
Agricultural labour	✓	
Agricultural transport costs	✓	
Capital (machinery/animal labour)		✓
Chick feeds prices	✓	
Cost of agricultural production	✓	
Daily transport cost	✓	
Diesel supply		✓
Fertiliser demand		✓
Fertiliser price	✓	
Fertilizer supply		✓
Fertilizers consumption		✓
Intermediate input (fertilizers / seeds)		✓
Irrigation		✓
Labour	✓	
Labour	✓	
Labour cost	✓	

Maize HYV adoption		✓
Millet HYV adoption		✓
Rice HYV adoption		✓
Sorghum HYV adoption		✓
Total factor productivity (bean)		✓
Total factor productivity (maize)		✓
Total factor productivity (rice)		✓
Total factor productivity (wheat)		✓
Total Labour	✓	
Use of HYV		✓
Wheat HYV adoption		✓

Labour	**Negative**	**Positive**
Agricultural wage		✓
Demand for labour		✓
Labour productivity		✓
Non agric. labour		✓
Return to labour		✓

Poverty	**Negative**	**Positive**
Capita expenditure		✓
Marginal returns to rural investment		✓
Poverty	✓	
Poverty level (head count ratio)	✓	
Reduction in number in poverty		✓
Reduction in number in poverty (rural)		✓
Reduction in number in poverty (urban)		✓
Rural poverty	✓	
Rural poverty	✓	
Variation in poverty	✓	
(blank)		✓

Prices	**Negative**	**Positive**
Chicken/duck prices		✓
Crop price (domestic)		✓
Crop price (international)		✓
Laspeyres agric. price index		✓
Laspeyres price index		✓
Product price (coffee/chocolate/cocoa)		✓
Product price (milk/butter/cheese)		✓
Rice prices		✓

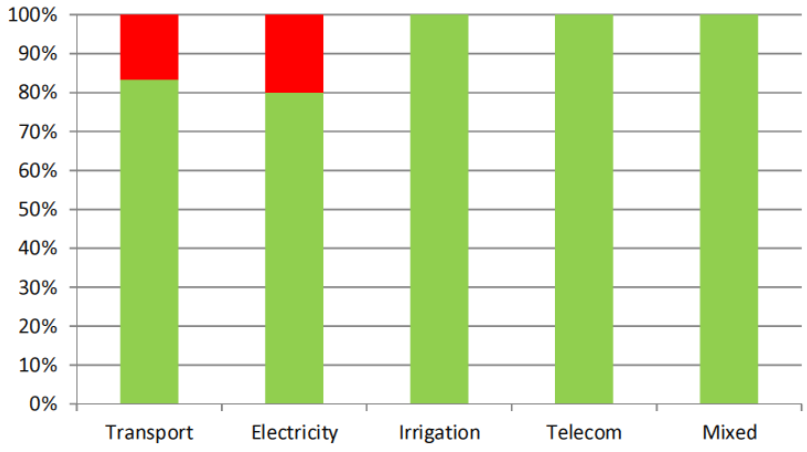
Production	**Negative**	**Positive**
Agricultural production Index		✓
Agriculture output		✓
Change grain area		✓
Change in cash crop area		✓
Change vegetable area		✓
Cotton yield		✓
Laspeyres agric. output index		✓

Maize yield		✓
No. chicken		✓
No. goats		✓
No. pigs		✓
No. sheep		✓
Non farm output		✓
Poultry mortality rate	✓	
Production function (model A)		
Production function (model B)		✓
Production growth		✓
Rice output		✓
Wheat yield		✓

Based on this classification, the impacts (positive, neutral, negative) on agricultural productivity were been assessed. The aggregated results, by impact indicator, are summarised in Sections 4.5.1 to 4.5.9.

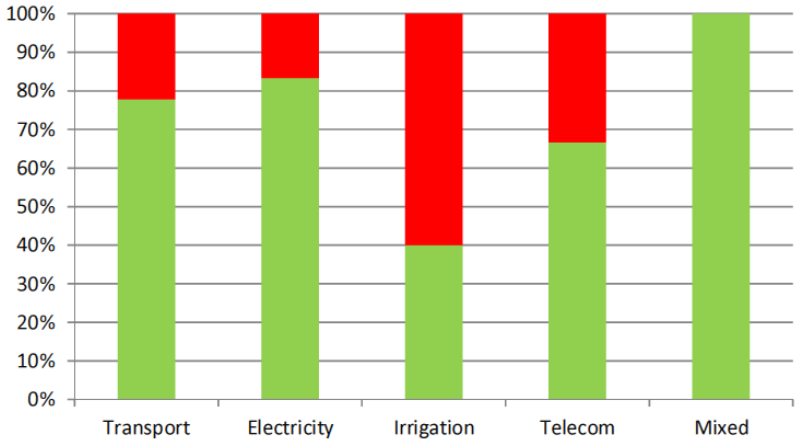
4.5.1 Indicator: Production

Indicator	**Positive effect**	**Neutral effect**	**Negative effect**	**Total**
Roads	10		2	12
Electricity	4		1	5
Irrigation	12			12
Telecom	3			3
Mixed	1			1
Total	**30**		**3**	**33**



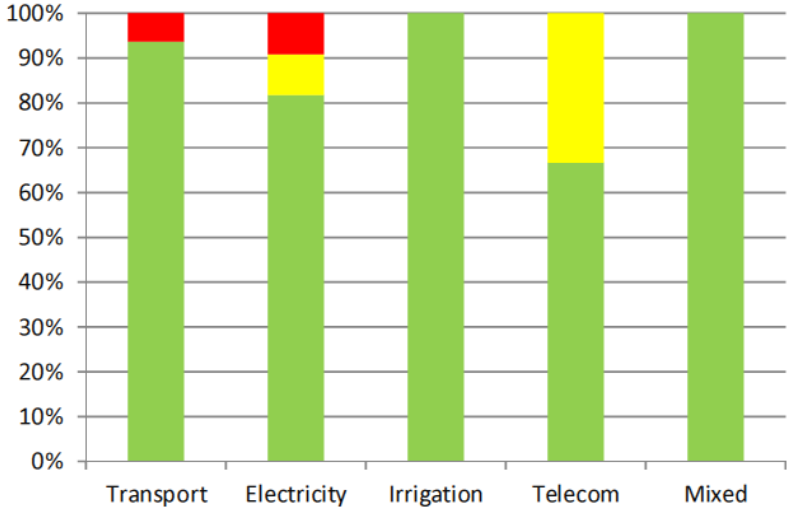
4.5.2 Indicator: Prices

Indicator	Positive effect	Neutral effect	Negative effect	Total
Roads	7		2	9
Electricity	5		1	6
Irrigation	2		3	5
Telecom	2		1	3
Mixed	3			3
Total	**19**		**7**	**26**



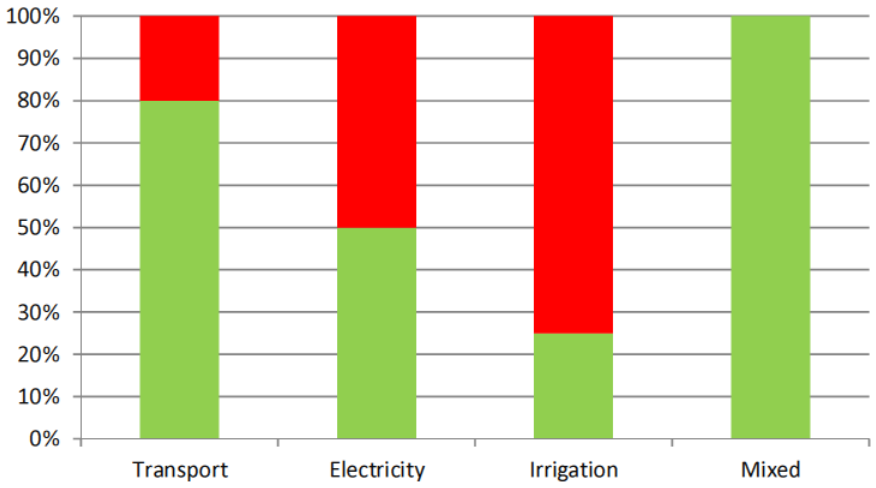
4.5.3 Indicator: Poverty

Indicator	Positive effect	Neutral effect	Negative effect	Total
Roads	30		2	32
Electricity	9	1	1	11
Irrigation	15			15
Telecom	2	1		3
Mixed	3			3
Total	**59**	**2**	**3**	**64**



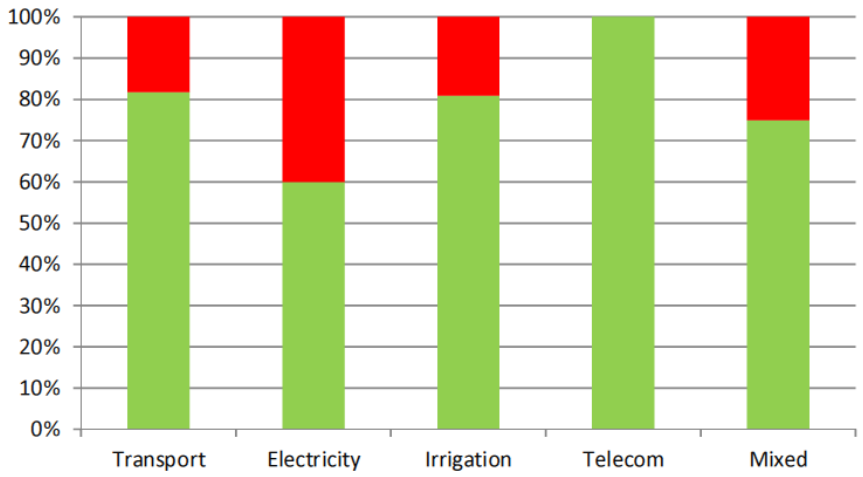
4.5.3 Indicator: Labour

Indicator	Positive effect	Neutral effect	Negative effect	Total
Roads	4		1	5
Electricity	1		1	2
Irrigation	1		3	4
Mixed	1			1
Total	**7**		**5**	**12**



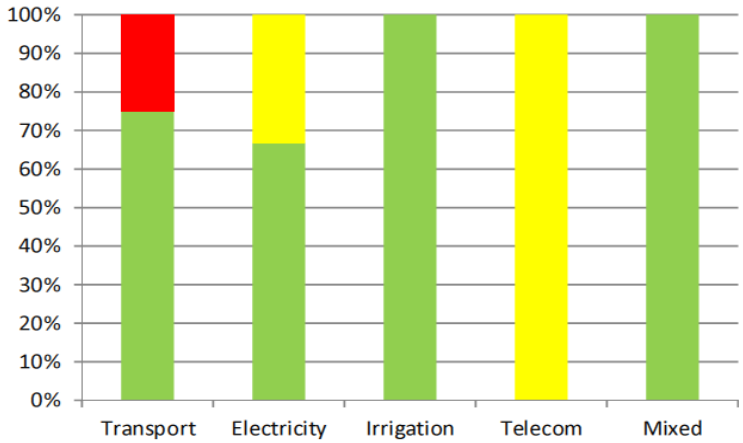
4.5.4 Indicator: Inputs

Indicator	Positive effect	Neutral effect	Negative effect	Total
Roads	9		2	11
Electricity	6		4	10
Irrigation	17		4	21
Telecom	3			3
Mixed	6		2	8
Total	**41**		**12**	**53**



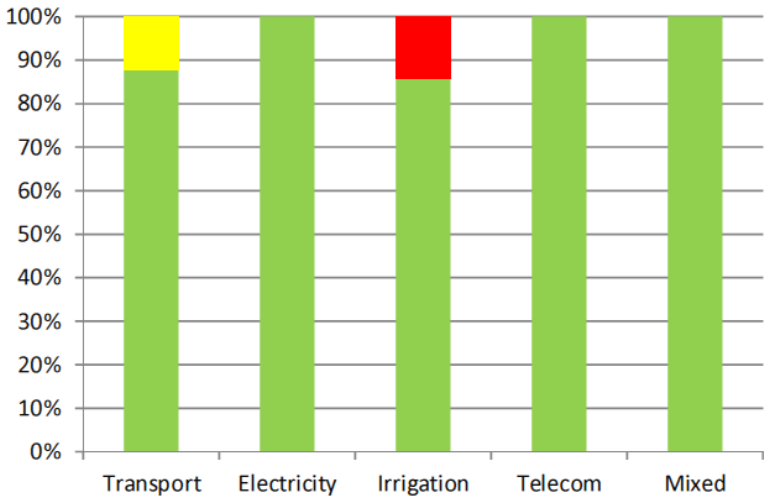
4.5.5 Indicator: Income

Indicator	Positive effect	Neutral effect	Negative effect	Total
Roads	3		1	4
Electricity	2	1		3
Irrigation	18			18
Telecom		1		1
Mixed	2			2
Total	**25**	**2**	**1**	**28**



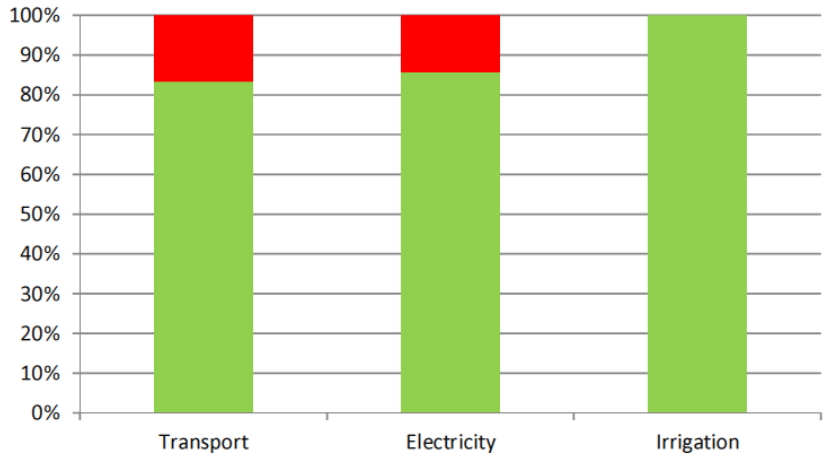
4.5.6 Indicator: GDP

Indicator	Positive effect	Neutral effect	Negative effect	Total
Roads	29	4		33
Electricity	5			5
Irrigation	6		1	7
Telecom	5			5
Mixed	3			3
Total	**48**	**4**	**1**	**53**



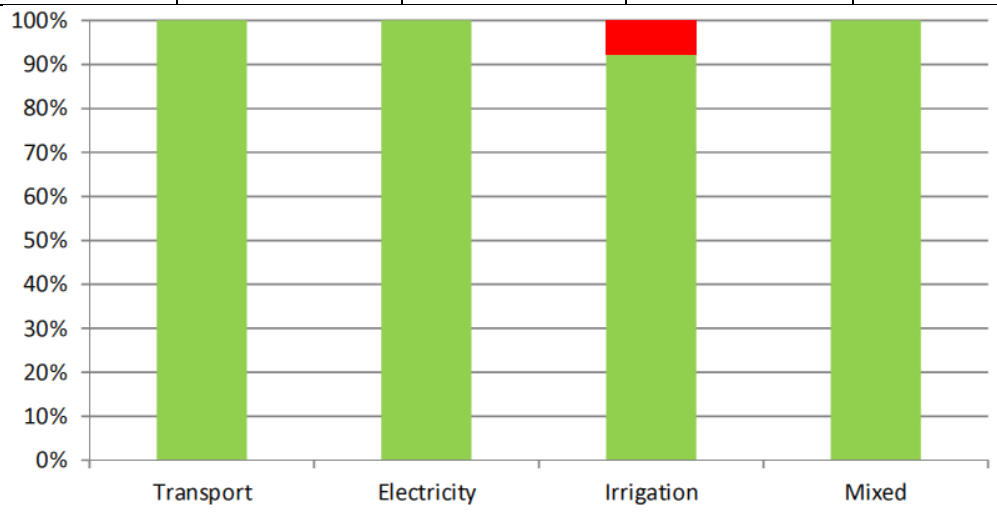
4.5.7 Indicator: Consumption

Indicator	Positive effect	Neutral effect	Negative effect	Total
Roads	5		1	6
Electricity	6		1	7
Irrigation	1			
Telecom				
Mixed				
Total	**12**		**2**	**14**



4.5.8 Indicator: Agricultural productivity

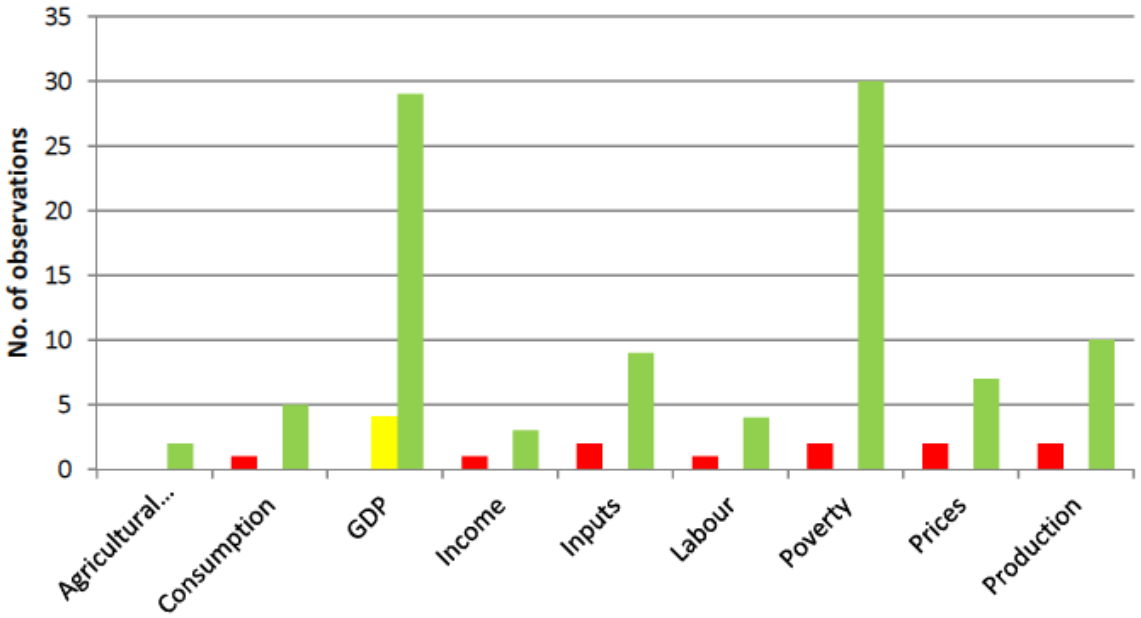
Indicator	Positive effect	Neutral effect	Negative effect	Total
Roads	2			2
Electricity	2			2
Irrigation	12		1	13
Telecom				
Mixed	7			7
Total	**23**		**1**	**24**



4.6 Quantitative analysis – by infrastructural investment area

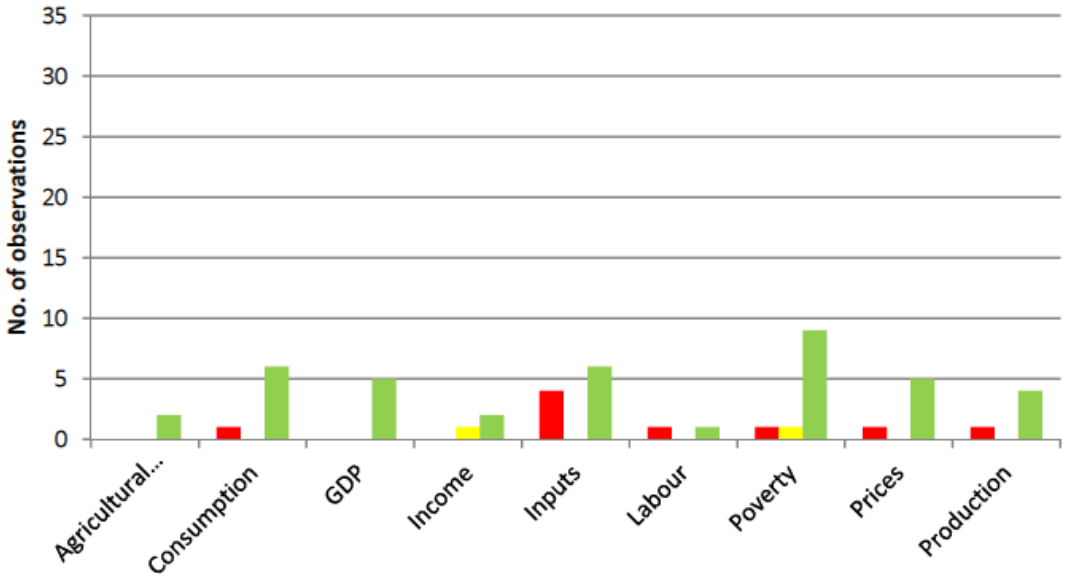
4.6.1 Roads infrastructure

Impact category	Positive effect	Neutral effect	Negative effect	Total
Agriculture	2			2
Consumption	5		1	6
GDP	29	4		33
Income	3		1	4
Inputs	9		2	11
Labour	4		1	5
Poverty	30		2	32
Prices	7		2	9
Production	10		2	12
Total	**99**		**11**	**110**



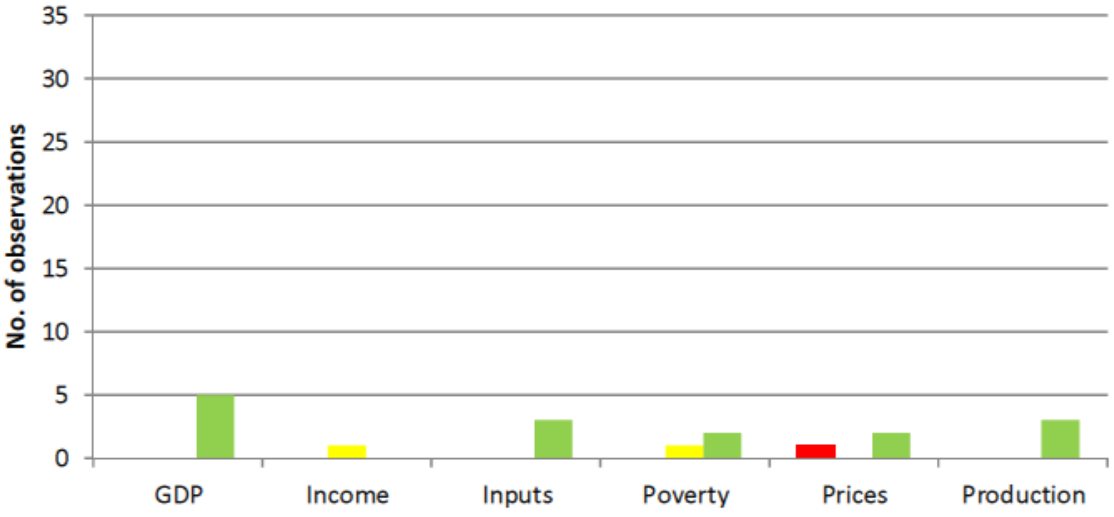
4.6.2 Electricity infrastructure

Impact category	Positive effect	Neutral effect	Negative effect	Total
Agriculture	2			2
Consumption	6		1	7
GDP	5			5
Income	2	1		2
Inputs	6		4	10
Labour	1		1	2
Poverty	9	1	1	11
Prices	5		1	6
Production	4		1	5
Total	**40**	**2**	**9**	**51**



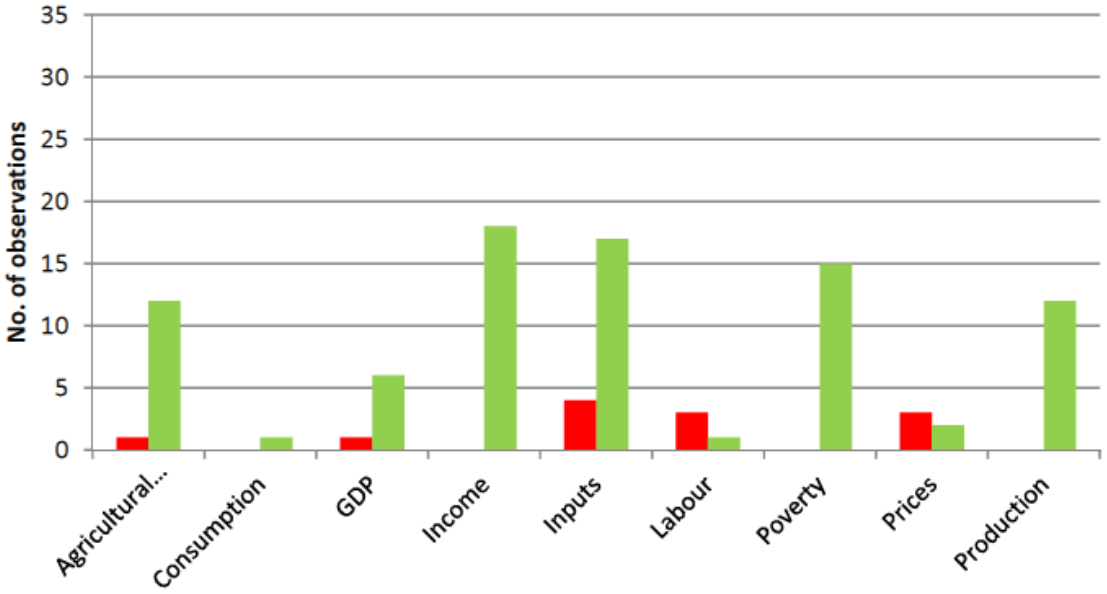
4.6.3 Telecommunications infrastructure

Impact category	Positive effect	Neutral effect	Negative effect	Total
Agriculture				0
Consumption				0
GDP	5			5
Income		1		1
Inputs	3			3
Labour		1		1
Poverty	2			2
Prices	2		1	3
Production	3			3
Total	**15**	**2**	**1**	**18**



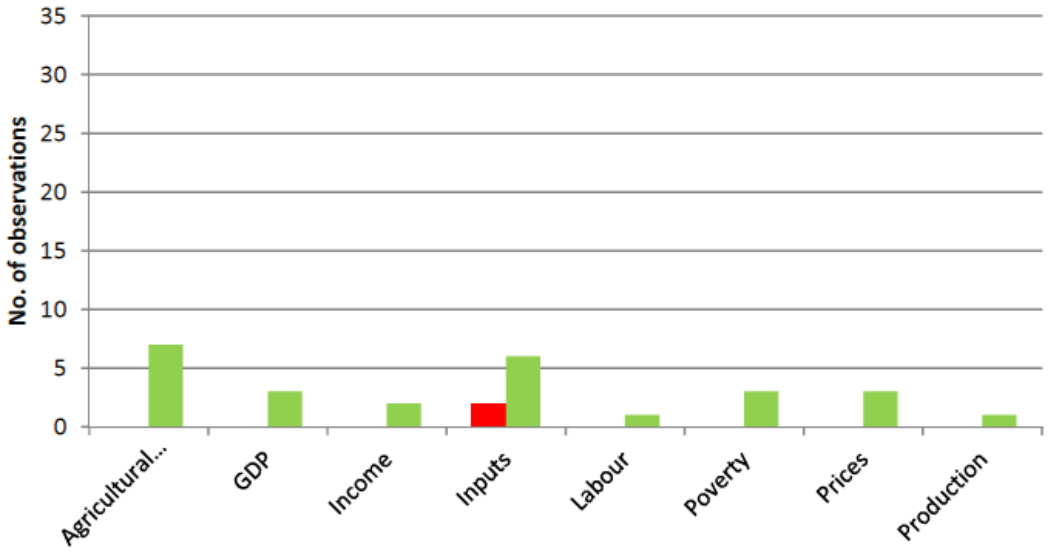
4.6.4 *Irrigation infrastructure*

Impact category	Positive effect	Neutral effect	Negative effect	Total
Agriculture	12		1	13
Consumption	1			1
GDP	6		1	7
Income	18			18
Inputs	17		4	21
Labour	1		3	4
Poverty	15			15
Prices	2		3	5
Production	12			12
Total	**84**		**12**	**96**



4.6.5 *Mixed infrastructure*

Impact category	Positive effect	Neutral effect	Negative effect	Total
Agriculture	7			7
Consumption				0
GDP	3			3
Income	2			2
Inputs	6		2	8
Labour	1			1
Poverty	3			3
Prices	3			3
Production	1			1
Total	**26**	**0**	**2**	**28**



5. Reviewer summary and methodological limitations

The articles used in this SR were based on statistical analysis of available data or data collected from surveys. The accuracy and their credibility can vary from one study to another depending on the data source, survey methodology, sample size and the scale on which the study is performed (district, village, national or global). The effect modifiers are another important issue with this type of analysis. The level of impact of infrastructure investment is therefore largely dependent on these modifiers and a positive implication/impact could quite easily become negative from one year to another or from one location to another. The difficulties found with this SR are that the results or evidence gathered can be highly biased by political, social and economic status of each study site and can vary spatially and temporally regardless the data accuracy or analysis methodology. In other words, what is applied and/or found in village or country "x" is not necessarily true for village or country "y".

With this internal variability or heterogeneity, a thorough quantitative synthesis was not possible; the narrative synthesis describes the implications of infrastructure investment in agriculture when applied under different various contexts. The narrative synthesis appears as a simple review of the literature but it follows a well-defined peer review protocol.

5.1 Implications for management and policy

Road infrastructure: Most evidence (37% of observations) related to this investment, and the majority of reported impacts on agricultural productivity were positive, particularly in relation to GDP gains and poverty reduction.

Electricity infrastructure: Limited evidence (16% of observations) on the impacts of electricity investment on agricultural productivity; but again more positive, especially for poverty reduction.

Telecommunication infrastructure: Very limited evidence (6% of observations) on the impacts of telecommunication, but the majority positive. The impacts for this area are most likely to be mixed in with other forms of infrastructural investment.

Irrigation infrastructure: A third of all evidence related to irrigation development, with the majority of impacts on agricultural productivity being positive, especially in relation to income and poverty reduction.

Mixed infrastructure: Most evidence found was positive.

5.2 Implications for research

The SR identified major gaps in knowledge on the direct impacts of investment in electricity and telecommunications infrastructure on agricultural productivity. This may not be surprising given that these types of investment are difficult to examine in isolation. The SR also identifies countries, regions and sectors where scientific information on the impact of infrastructure investment on agriculture is absent, weak, or inconclusive. It is within these areas, that strategic research should be targeted to fill existing gaps in knowledge.

6. Potential conflicts of interest and sources of support

There were no known sources of conflict. The study was funded by the UK Department of International Development (DFID).

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