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The Impacts of Infrastructure in Development: A Selective Survey

Yasuyuki Sawada

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Yasuyuki Sawada is a professor at the Graduate School of Economics, Faculty of Economics, University of Tokyo.

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Please contact the author for information about this paper.

Email: sawada@e.u-tokyo.ac.jp

Asian Development Bank Institute
Kasumigaseki Building 8F
3-2-5 Kasumigaseki, Chiyoda-ku
Tokyo 100-6008, Japan

Tel: +81-3-3593-5500
Fax: +81-3-3593-5571
URL: www.adbi.org
E-mail: info@adbi.org

Abstract

Development economists have considered physical infrastructure to be a precondition for industrialization and economic development. Yet, two issues remain to be addressed in the literature. First, while proper identification of the causal effectiveness of infrastructure in reducing poverty is important, experimental evaluation, such as randomized control trials (RCT)-based evaluation, is difficult in the context of large-scale infrastructure. Second, while micro studies so far have focused on the nexus between infrastructure and certain types of poverty outcomes such as income, poverty, health, education, and other individual socio-economic outcomes, to better interpret a wide variety of micro-level infrastructure evaluation results using either experimental or non-experimental methods, the role of infrastructure should be placed in a broader context. To bridge these gaps, we augment the existing review articles on the same topic, such as Estache (2010), Hansen, Andersen, and White, (2012), and World Bank (2012) by addressing these two remaining issues. First, while forming a counterfactual is often difficult for impact evaluation of infrastructure, engineering constraints beyond human manipulation can allow people to adopt quasi-experimental methods of impact evaluation. Second, evaluators can adopt, for example, a hybrid method of natural and artefactual field experiments to elicit the role of infrastructure in facilitating the complementarity of the market, state, and community mechanisms.

JEL Classification: C93, H54, O1, O18

Contents

1. INTRODUCTION

Development economists have considered physical infrastructure to be a precondition for industrialization and economic development, where physical infrastructure, in general, consists of two parts: economic infrastructure such as telecommunications, roads, irrigation, and electricity; and social infrastructure such as water supply, sewage systems, hospitals, and school facilities (Murphy, Shleifer, and Vishny 1989). It has been demonstrated that physical infrastructure development improves the long-term production and income levels of an economy in both the macroeconomic endogenous growth literature (Barro 1990; Futagami, Morita, and Shibata 1993) and empirical studies (Easterly and Rebelo 1993; Lipton and Ravallion 1995; Jimenez 1995; Canning and Bennathan 2000; Esfahani and Ramirez 2003; Canning and Pedroni 2008; Calderón, Moral-Benito, and Servén 2014). Moreover, a number of micro studies have shown that development of infrastructure is one of the indispensable components of poverty reduction (Van de Walle 1996; Lokshin and Yemtsov 2005; Jalan and Ravallion 2003; Jacoby 2000; Gibson and Rozelle 2003).

Macroeconomic theories and empirical studies clearly characterize the aggregate impacts of infrastructure in an economy. But such studies fail to address heterogeneous access to and the impact of infrastructure in individual economies. This is a serious limitation because recent studies show, for example, that access to intra-regional infrastructure is highly skewed toward the richest, due to differences in physical access and affordability (Estache and Fay 2007).

On the other hand, existing micro-econometric studies provide insights into the role of infrastructure in improving productivity and reducing poverty. However, two issues remain to be addressed. The first important issue is the proper identification of the causal effectiveness of infrastructure in reducing poverty. Experimental evaluation, such as randomized control trials (RCT)-based evaluation, which has been developing rapidly, especially in the education and health sectors (Duflo, Glennerster, and Kremer 2008), is difficult to carry out in the context of large-scale infrastructure. A notable exception is a study by Gonzalez-Navarro and Quintana-Domeque (2012), who conduct a randomized street asphalting experiment to quantify the impact of infrastructure development on poverty reduction. Hence, those engaging in rigorous evaluation of infrastructure started employing quasi-experimental methods such as natural experimental approaches (Duflo and Pande 2007; Jensen 2007; Dinkelman 2011; Donaldson 2013).

The second issue is to adopt the broader framework to evaluate the role of infrastructure in reducing poverty because, obviously, infrastructure cannot exist in isolation. All the micro studies conducted so far have focused on the nexus between infrastructure and certain types of poverty outcomes such as income, poverty, health, education, and other individual socio-economic outcomes. While such micro-econometric studies have provided insights into the role of infrastructure in reducing poverty, the adopted frameworks are rather limited. For example, most of the earlier micro studies on the nexus between infrastructure and poverty reduction employ a static concept of poverty, even though most recent poverty studies have focused on its dynamic and stochastic nature (Dercon 2005; Fafchamps 2003). It has been established that policy analyses based on static poverty can result in inefficient policy interventions (Jalan and Ravallion 1998). Moreover, there is no consensus on the "channels" through which infrastructure development reduces poverty. Access to infrastructure not only increases household income directly by improving production; it also has indirect effects, such as changing consumption, saving, and investment decisions as well as facilitating accumulation of social capital (Aoyagi et al. 2014; Dillion 2011), which is defined as formal and informal institutions and organizations that create shared knowledge, mutual trust, social norms, and unwritten rules. (Dasgupta and Serageldin 2000; Durlauf and Fafchamps 2005; Hayami 2009). To better interpret a wide variety of infrastructure evaluation results using either experimental or non-experimental methods, infrastructure's role should be regarded as a facilitator of strengthening mutual complementarities between market, state, and community mechanisms, as community mechanisms play a critical role in correcting both market and government failures (Hayami 2009; Mansuri and Rao 2013).

While there are three excellent recent review articles covering a wide range of impact evaluations of infrastructure projects (Estache 2010; Hansen, Andersen, and White 2012; World Bank 2012), this paper aims to discuss the two remaining issues as mentioned above. The rest of the paper is organized as follows. In Section 2, we review the existing studies on infrastructure impact estimation, using either non-experimental or experimental methods. Section 3 discusses the broader impacts of physical infrastructure, followed by the concluding remarks in Section 4.

2. INFRASTRUCTURE IMPACT ESTIMATION

Table 1 shows conventional estimates of aggregate overall infrastructure productivity captured by elasticity of output with respect to infrastructure access, summarizing reviews by Jimenez (1995), Munnel (1990), and World Bank (1994), and other recent studies. Except for the study using US data (Holtz-Eakin 1992), the estimated elasticities are all positive, ranging from 0.01 to 0.39. In the latest comprehensive study on infrastructure impacts, Calderón, Moral-Benito, and Servén (2014) employed a panel time series approach using a large cross-country dataset to estimate a long-run aggregate production function relating gross domestic product (GDP) to human capital, physical capital, and a synthetic measure of infrastructure comprising transport, power, and telecommunications. In their estimation results, the long-run elasticity of output with respect to the synthetic infrastructure index ranges from 0.07 to 0.10. In Table 2, aggregate elasticity estimates for output with respect to transportation and irrigation infrastructure are presented. The point estimates are mostly positive, ranging from 0.07 to 1.62, and falling in the range of the estimated elasticities for aggregate infrastructure productivity reported in Table 1.

Table 1: Conventional Estimates of Aggregate Infrastructure Productivity in Elasticity of Output with respect to Infrastructure Access

Economy/Region	Infrastructure Type	Elasticity	Source
United States	Non-military public capital	0.39	Aschauer (1989)
United States	Non-military public capital	0.34	Munnel (1992)
United States, 48 states	Public capital	0	Holtz-Eakin (1992)
Japan, regions	Industrial infrastructure	0.20	Mera (1973)
Taipei,China	Transportation, water, and communication	0.24	Uchimura and Gao (1993)
Republic of Korea	Transportation, water, and communication	0.19	Uchimura and Gao (1993)
Mexico	Power, communication, and transportation	0.05	Shah (1992)
Cross-country, OECD and LDCs	Infrastructure capital stocks	0.01–0.16	Baffes and Shah (1998)
Cross-country	Transportation, power, and telecommunication	0.07–0.10	Calderón, Moral-Benito, and Servén (2014)

OECD = Organisation for Economic Co-operation and Development; LDCs = least developed countries.

Source: Author’s update of Box Table 1.1 in World Bank (1994).

Table 2: Conventional Estimates of Aggregate Transportation and Irrigation Infrastructure Productivity in Elasticity of Output with respect to Infrastructure Access

Economy/Region	Infrastructure Type	Elasticity	Source
Cross-country	Paved roads in agriculture	0.26	Binswanger (1990)
Cross-country	Rural road density in agriculture	0.12	Binswanger (1990)
Cross-country, OECD	Transportation	0.07	Canning and Fray (1993)
Cross-country, LDCs	Transportation	0.07	Canning and Fray (1993)
Cross-country, LDCs	Transportation and communication	0.16	Easterly and Rebelo (1993)
India, districts	Road	0.20	Binswanger and Khandker (1993)
Cross-country	Irrigation in agriculture	1.62	Binswanger (1990)
India, districts	Irrigation	0.00	Binswanger and Khandker (1993)

OECD = Organisation for Economic Co-operation and Development; LDCs = least developed countries.

Source: Author’s update of Table 43.1 of Jimenez (1995) and Box Table 1.1 in World Bank (1994).

As to more recent studies on the impacts of infrastructure, Hulten, Bennathan, and Srinivasan (2006) found that in India, from 1972 to 1992, highways and electricity accounted for almost half of the growth of the Solow residuals of the manufacturing industries. The positive productivity effects of physical infrastructure development can be found even in rural areas and agricultural sectors (Jimenez 1995; Fan and Zhang 2004; and Zhang and Fan 2004). Table 2 also includes estimates of positive production elasticities with respect to road and irrigation infrastructure in agriculture. Among more recent studies, del Carpio et al. (2011), Dillion (2011), and Strobl and Strobl (2011) used unique datasets to evaluate the impact of irrigation on production and consumption. Based on the findings of these existing studies on positive productivity impacts of infrastructure and a strong positive correlation between income growth and poverty reduction found in various studies, such as Besley and Burgess (2003), Dollar and Kraay (2000), and Ravallion (2001), it is evident that infrastructure development is likely to reduce poverty by enhancing growth.

Empirical studies have increasingly started to focus on the role of infrastructure in reducing poverty directly. Such studies include: Datt and Ravallion (1998) on state-level poverty in India; Van de Walle (1996) on the poverty reduction effect of irrigation infrastructure in Viet Nam; Jalan and Ravallion (2003) on the water supply system; Lokshin and Yemtsov (2004, 2005) on the poverty reduction effect of community-level infrastructure improvement projects on water supply systems in Georgia; Brockerhoff and Derose (1996) and Jalan and Ravallion (2003) on the role of water supply and public health systems; and Jacoby (2000), Gibson, and Rozelle (2003), and Jacoby and Minten (2008) on the effectiveness of road and transportation infrastructure.

In a more recent study, Sawada, Shoji, Sugahara, and Shinkai (2014) identified a relationship between infrastructure development and poverty reduction with regard to seasonal fluctuations in consumption expenditure, using a unique panel data set of irrigated and unirrigated areas of Southern Sri Lanka. They found that irrigation reduces chronic poverty by improving permanent income and eliminates the negative impact of transient poverty by reducing downside expenditure risk. These findings are consistent with theoretical implications of a canonical model of intertemporal consumption decisions under potentially binding credit constraints. Their results provide evidence in support of the role of infrastructure in reducing both chronic and transient poverty.

2.1 Experimental and Quasi-Experimental Studies

However, such non-experimental studies are likely to involve upward biases in estimating elasticities because infrastructure is placed in areas where economic growth is expected and/or the hosting communities have appropriate capacities. To illustrate this problem, consider a framework of each outcome variable, *Y,* and a dichotomous variable for infrastructure access, *D*, which takes the value of one if there is access, and zero otherwise. In other words, we postulate a model of "treatment" of infrastructure access. The level of an outcome variable with infrastructure is denoted by Y^1, and without infrastructure by Y^0. The average impact on outcome caused by infrastructure can be captured by the following average treatment effects of the treated (*ATT*):

$$(1) \qquad E(Y^1 – Y^0|D=1).$$

In equation (1), the fundamental issue is the way to grasp the counterfactual outcome, $E(Y^0|D=1)$, which cannot be observed directly. We can write and expand the observable average difference between the treatment and control groups by the following equation:

$$(2) \qquad E(Y^1|D = 1) – E(Y^0|D = 0)$$
$$= [E(Y^1 = 1|D = 1) – E(Y^0|D = 1)] + [E(Y^0|D = 1) – E(Y^0|D = 0)]$$
$$= E(Y^1 – Y^0|D = 1) + [E(Y^0|D = 1) – E(Y^0|D = 0)].$$

Equation (2) shows that the observable average difference between the treatment and control groups, i.e., $E(Y^1|D = 1) – E(Y^0|D = 0)$, deviates from *ATT*, $E(Y^1 – Y^0|D = 1)$, by the amount $E(Y^0|D = 1) – E(Y^0|D = 0)$. This discrepancy is called a selection bias, which basically shows the discrepancy between the average outcome of counterfactual situation $E(Y^0|D = 1)$ and the average observable outcome of the control group $E(Y^0|D = 0)$. If infrastructure is placed in the areas or for the groups which have a better outcome even without infrastructure, the selection bias will be positive, i.e., $E(Y^0|D = 1) – E(Y^0|D = 0)>0$, generating upward bias in estimating *ATT*.

To mitigate these biases and to accurately identify the causal impacts of infrastructure, it is more appropriate to employ experimental or quasi-experimental methods, which carefully utilize situations in which there is no selection bias. In fact, analytically robust evaluation of infrastructure has been an emerging field in development economics and policymaking recently. If random placement of infrastructure is possible, we can set $E(Y^0|D = 1) - E(Y^0|D = 0)$ intentionally. Yet, such randomization will be difficult for infrastructure projects due to their large-scale aggregate nature. Even in this case, when infrastructure placements are determined by factors that cannot be manipulated by humans, they provide researchers with natural experiments similar to those found in DiNardo (2008), in which people are exogenously assigned into treatment and control groups. We assume that such a natural experiment gives us a serendipitous situation where the selection bias $[E(Y^0|D = 1) - E(Y^0|D = 0)]$ converges to zero. We can also work with a weaker condition under which, given the same set of observables X, the selection bias becomes zero, i.e.,

(3) $$E(Y^0|D = 1, X) - E(Y^0|D = 0, X) = 0.$$

This assumption is called ignorability, or selection on observables.

Table 3 shows experimental estimates of outcome elasticity with respect to infrastructure access. As a notable example of impact evaluation of infrastructure using a quasi-experimental method, Duflo and Pande (2007) performed impact evaluation of dams in India on poverty reduction, using river gradient variables as instrumental variables for placements of dams for engineering reasons. Using district-level data from India, they found that in districts located downstream from a dam, agricultural production increases, rural poverty and vulnerability to rainfall shocks decline, agricultural production shows an insignificant increase, and poverty increases in the district where the dam is located, but its volatility increases. These results suggest that neither markets nor state institutions have alleviated the adverse distributional impacts of dam construction.

Table 3: Experimental Estimates of Outcome Elasticity with respect to Infrastructure Access

Economy/Location	Infrastructure Type	Outcome Measure	Elasticity	Source
India, districts	Railway network	Agricultural income per acre	0.157–0.188	Donaldson (2014)
Kerala, India	Mobile phone network	Consumer and producer welfare	Positive	Jensen (2007)
South Africa	Rural electrification	Female employment	0.3–0.35	Dinkelman (2011)
Acayucan, Mexico	Road asphalting	Durable and home ownership	0.12–0.50	Gonzalez–Navarro and Quintana–Domeque (2012)
People’s Republic of China, cities and counties	Road network	GDP	0.07	Banerjee, Duflo, and Qian (2012)
India, districts	Dams	Agricultural production	0.3 (downstream) 0 (upstream)	Duflo and Pande (2007)

GDP = gross domestic product.

Source: Author’s compilation.

Dinkelman (2011) followed a similar identification strategy to quantify the impact of household electrification on employment in South Africa. Since electricity infrastructure construction is constrained by geographical conditions, land gradient information is utilized as an instrumental variable for electrification. This paper found that electrification significantly raises female employment within 5 years while reducing female wages and increasing male earnings. Several pieces of evidence also suggest that household electrification raises employment by releasing women from household-related tasks and enabling the formation of microenterprises

Jensen (2007) evaluated the impact of mobile phones in India's Kerala state on the price of sardines, a perishable good formerly lacking in appropriate cold chain networks. He utilized a nature of the mobile phone network developments in which the timing of the introduction of mobile phones in each fishing community is different and is exogenously given to fishermen. Using micro-data, he showed that the adoption of mobile phones by fishermen and wholesalers is associated with a dramatic reduction in price dispersion, the complete elimination of waste, near-perfect adherence to the Law of One Price, and significant increases in both consumer and producer welfare.

Donaldson (2014) employed a general equilibrium trade model and archival data from colonial India to investigate the impact of India's vast railroad network. The study found that railroad infrastructure reduced trade costs and interregional price gaps; increased interregional and international trade; increased real income levels; and generated substantial gains from trade.

Banerjee, Duflo, and Qian (2012) used historical data from cities and counties in the People's Republic of China on transportation networks to estimate the effect of access to transportation networks on regional economic outcomes in the People's Republic of China over a 20-year period of rapid income growth. This paper addressed the problem of the endogenous placement of networks by exploiting the fact that these networks tend to connect historical cities, showing that proximity to transportation networks have a moderate positive causal effect on per capita GDP levels across sectors, but no effect on per capita GDP growth. Based on a simple theory, the authors argue that their results are consistent with factor mobility playing an important role in determining the economic benefits of infrastructure development.

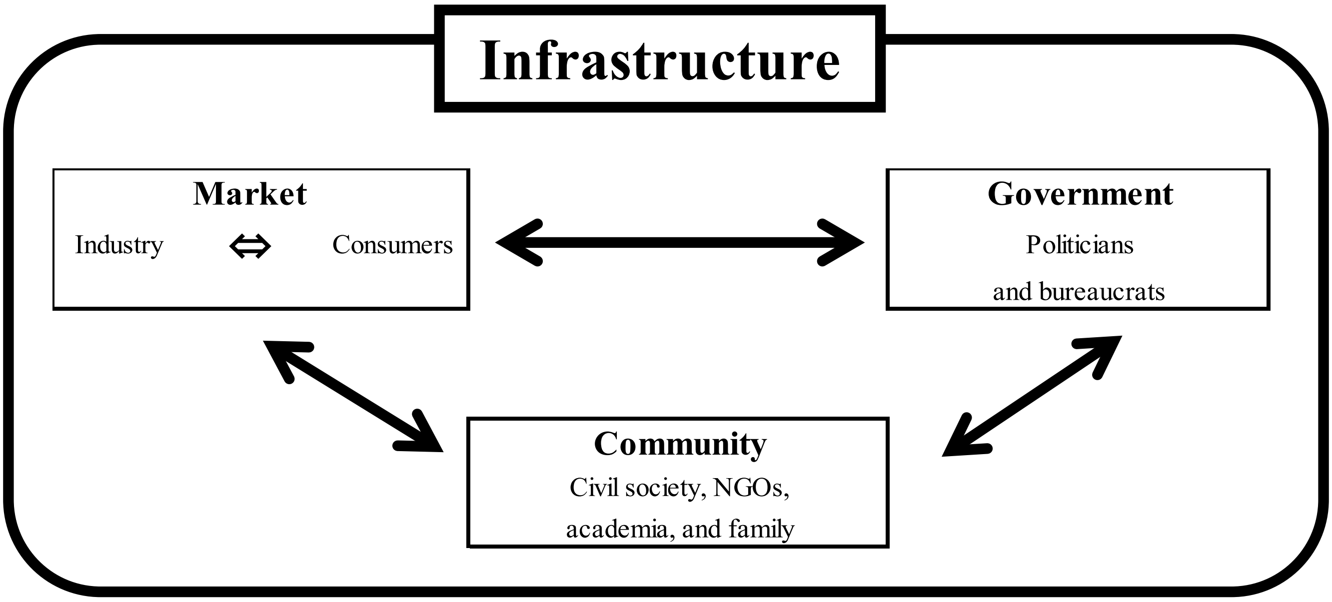
Gonzalez-Navarro and Quintana-Domeque (2012) used a first-time street asphalting randomized experiment to provide experimental evidence on the role of infrastructure in reducing poverty for the urban poor. Within 2 years of the intervention, households whose streets were finally paved, and who were present both before and after its implementation, increased their consumption of durable goods and acquired more motor vehicles. These impacts were driven in part by street pavement boosting housing wealth, which fueled a rise in collateralized credit use, but also by an increase in the marginal utility of vehicles.

3. EVALUATION OF BROADER IMPACTS

While these studies provide high-quality impact estimation for each infrastructure type in each economy or region, we should be aware that infrastructure cannot exist in isolation. These estimates based on reduced-form models, or a "black box" approach, may mask the important causal mechanisms and spillover effects behind observed impacts of infrastructure. To better interpret a wide variety of infrastructure evaluation results using either experimental or non-experimental methods, we can ask a fundamental question: what is the role of infrastructure in a society as a whole? A textbook explanation goes as follows. The market is the mechanism that uses price signals to coordinate profit-seeking individuals and firms. But market mechanisms often fail to efficiently allocate resources because of externalities, the existence of public goods, information problems, and the lack of effective property rights. To correct such market failures, the state provides other mechanisms to force people to adjust their resource allocations. Especially, the state plays an important role in supplying global or pure public goods including infrastructure. In other words, a lack of infrastructure implies the presence of uncorrected market failures in an economy. According to this logic, existing evaluation studies presume that government or donor intervention is indispensable for providing infrastructure in order to mitigate market failures and improve resource allocation. However, the state can also fail because politicians, bureaucrats, and donor agencies often pursue their own objectives.[1] Local participation is seen as the most effective and sustainable way of redressing local government failure—tackling corruption, giving the poor a greater say in policy decisions, and holding local governments more accountable (Mansuri and Rao 2013).

In this context, we can adopt Hayami's (2009) framework which connects the role of community to the market and state mechanisms (Figure 1). The community is the mechanism that uses social capital to promote voluntary cooperation, facilitating the supply of local public goods such as construction and maintenance of physical infrastructure, conservation of the commons, and enforcement of informal transactions. By using social capital, the community thus plays a critical complementary role in correcting both market and government failures.

Figure 1: Infrastructure for the Trinity of Community, Market, and Government



NGOs = non-governmental organizations.

Source: Author's figure based on Hayami (2009).

[1] For different motives of donors, see, for example, Alesina and Dollar (2000).

The complementarity of market, state, and community can be understood through use of the prisoner's dilemma game, in which the profit-seeking behavior of self-interested group members leads to a sub-optimal outcome or non-Pareto efficient "Nash equilibrium." This is a canonical example of market failure where a laissez-faire system does not result in a socially optimal "Pareto efficient" outcome. This type of market failure can be corrected theoretically by the state's legal enforcement framework. If we follow the logic of Hayami (2009), social capital should also play an important role in avoiding the prisoner's dilemma situation by complementing the lack of effective market and state mechanisms. In this review, the role of physical infrastructure is taken as an instrument of facilitating mutual complementarities in the trinity of the market, state, and community mechanisms (Figure 1).

To illustrate this argument in a concrete manner, let us use irrigation infrastructure as an example. Irrigation involves substantial cooperative work and collective action problems among community members, as the maintenance and productive use of the irrigation system require regular cleaning of the canals, necessitating coordination and cooperation among community members (Ostrom 2011; Aoki 2001; Hayami and Godo 2005). This feature of irrigation infrastructure helps us to clearly identify the determinants of the community mechanism. There have been several studies hypothesizing about the role of irrigation and other communal physical infrastructure in facilitating social capital accumulation (Aoki 2001; Hayami and Godo 2005; Hayami 2009).

In this context, Aoyagi, Sawada, and Shoji (2014) investigated the impact of physical infrastructure on social capital accumulation by comparing two hypotheses: the habit formation hypothesis and the repeated interaction hypothesis of social capital. They used a unique dataset from an irrigation project in Sri Lanka under a natural experimental situation in which a significant portion of irrigated land was allocated through a lottery mechanism. Also, they elicited the level of social capital using an artefactual field experiment such as trust games by a strategy method based on a within-subject design. By means of a hybrid experiment of the natural experiment and the artefactual field experiment, they found that physical distance embedded in irrigation systems explain variations in trust across irrigation communities, suggesting that the level of particularized trust is significantly higher than that of generalized trust. Also, within-community variation in particularized trust is driven largely by each individual's years of access to irrigation and is not necessarily affected by social distance or repeated interaction among farmers. Their results indicate that social preference emerges from a technological environment determined by physical access to irrigation, supporting the habit formation of the pro-social behavior hypothesis.

From the findings of Aoyagi, Sawada, and Shoji (2014), we can derive broader implications regarding the role of infrastructure construction in developing countries, where market mechanisms for resource allocation are generally underdeveloped. To correct such market failures, the state has other mechanisms to force people to adjust their resource allocations. But the state can also fail, especially in developing countries where governance is generally weak. In contrast, the community is the mechanism that uses social capital to promote voluntary cooperation, facilitating the supply of local public goods. Social capital thus plays a critical complementary role in correcting both market and government failures (Hayami 2009). In fact, the complementarity between the market and social capital can be better understood by the trust game adopted in their study (Sawada 2014). The trust game is a version of the prisoner's dilemma game, representing market failure, in which laissez-faire cannot achieve an efficient outcome and thus the "Nash equilibrium" is socially sub-optimal. In the trust game, levels of trust are defined as the extent to which the observed outcome deviates away from the socially inefficient Nash equilibrium and toward the social optimal level. In other words, the trust level elicited by the trust game captures complementarity between market mechanisms and social capital.[2] Their empirical results indicate that such a complementarity can be strengthened by investments in irrigation infrastructure and resulting habit formation of pro-social behavior. In sum, infrastructure can play an important role in amending market and government failures by solving the prisoner's dilemma problem.

4. CONCLUDING REMARKS

In this survey article on impact evaluation of infrastructure, we augment the coverage in the existing review article on the same topic by addressing two remaining issues: first, the proper identification of the causal effectiveness of infrastructure in reducing poverty; and, second, the broader complementarities in the trinity of the market, state, and community mechanisms. As to the first issue, while forming a counterfactual is often difficult for impact evaluation of infrastructure, engineering constraints beyond human manipulation can allow people to adopt the canonical methods of impact evaluation.

As to the second issue, evaluators of infrastructure projects need to place them in a broader community framework, correcting both market and government failures. As a methodological instrument, evaluators can adopt, for example, a hybrid method of natural and artefactual field experiments to elicit the role of infrastructure in facilitating the complementarity of the market, state, and community mechanisms.

We confined our coverage to economic infrastructure such as telecommunications, roads, irrigation, and electricity, excluding social infrastructure such as water supply, sewage systems, hospitals, and school facilities. Moreover, broader infrastructure such as market and institutional infrastructures are not discussed in this paper. Further exploration of these wider impacts of infrastructure development should be pursued in future studies.

[2] Karlan (2005) found this complementarity among microcredit clients in Peru.

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