Bridge to Bigpush or Backwash? Market Integration, Reallocation, and Productivity Effects of Jamuna Bridge in Bangladesh

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Abstract

This paper uses a quasi-experimental study of a major bridge construction in Bangladesh to understand the effects of a large reduction in trade costs on the pattern of structural change and agricultural productivity. We develop a spatial general equilibrium model with a core and two hinterlands at the opposite sides separated by rivers, and allow for productivity gains through agglomeration in both agriculture and manufacturing sectors. The model yields insights different from the standard core-periphery and trade models: (i) the newly connected hinterland may experience higher population density and agricultural productivity despite significant deindustrialization, (ii) even with increased specialization in agriculture, the share of agricultural employment may decline when inter-regional trade requires local services (e.g. processing and trading), and (iii) the strongest effects on employment structure are felt not necessarily in the areas next to the bridge but in the areas that move out of autarky as a result of the bridge.

In empirical estimation, we use doubly robust estimators in a difference-in-difference design where the comparison hinterland comes from a region which was supposed to be connected to the core (capital city) by the proposed, but not yet constructed, Padma bridge. In the short run, we find significant labor reallocation from agriculture to services in the connected hinterland, but no perceptible effects on the employment share of manufacturing, population density and night-lights. In the long run, the labor share of manufacturing declines in the treatment hinterland and increases in the core. However, there are significant positive effects on population density, night light luminosity and agricultural yields in the treatment hinterland which contradict backwash effects of bridge. The effects of bridge on intersectoral labor allocation are spatially heterogeneous, with relatively weak effects in the areas close to the bridge.

Keywords: Core-Periphery, Density, Agricultural Productivity, Bridge
JEL Classification: R40; R13; O18; O13; O14

(1) Introduction

The benefits of spatial integration of segmented markets are widely accepted among policy makers, improvements in allocational and production efficiency due to enhanced competition are usually identified as the mechanisms at work. Public investment in transport infrastructure projects such as roads and bridges in developing countries is often underpinned by this policy perspective. Economic theory is, however, less sanguine about the effects of market integration. The caveats about efficiency and equity effects of market integration from the theory of second best and Diamond and Mirrlees production efficiency theorem are well-understood (for excellent discussions, see Hammond (1993), Donaldson (2015)).[1] An influential strand of the literature that goes back at least to Myrdal (1957) and is formalized in the core-periphery models following Krugman (1991) emphasizes the spatial aspects, and underscores the possibility that integration with the urban centers may result in "backwash effect", as resources leave the newly connected hinterland and high productivity manufacturing concentrates in the urban core (see Fujita, Krugman, and Venables (1999), Fujita and Thiesse (2002), Baldwin et al. (2003)). The worry that market liberalization and integration may cause deindustrialization and exacerbate spatial inequality has been a persistent policy concern in both developing and developed countries, and spawned a variety of policies that use geographic targeting to address poverty, unemployment, and inequality (for excellent surveys, see Moretti and Kline (2014a), Breinlich et al. (2014), Kanbur and Venables (2005)).

This paper uses a quasi-experimental study of a major bridge construction in Bangladesh, the Jamuna bridge, to understand the effects of a large reduction in trade costs on the pattern of resource allocation, agricultural productivity and structural change in an underdeveloped economy. The 4.8 kilometer long Jamuna bridge opened in 1998, and spanning over one of the largest rivers in the world, connected about 26 million people residing in the chronically poverty-ridden areas in the Northwest Bangladesh to the growth centers in the East including the capital city Dhaka and the port city Chittagong. By conservative estimates, the bridge reduced the freight costs by 50% and travel time from areas in north-west to Dhaka city by 3-4 hours.

We develop a spatial general equilibrium model of an economy with a core and two hinterlands

[1] When the initial allocation is inefficient, enhanced competition due to market integration can exacerbate distortions, consistent with the theory of second best (Helpman and Krugman (1985)). The desirability of production efficieny hinges on important assumptions, for example, no informal sector or absence of untaxed profit for firms (Dasgupta and Stiglitz (1974), Emran and Stiglitz (2005)). These assumptions are clearly violated in developing countries.

at the opposite sides separated by rivers. In contrast to the core-periphery models where only the manufacturing sector enjoys agglomeration externalities, we allow for productivity gains through agglomeration in both agriculture and manufacturing sectors in response to bridge construction connecting one of the hinterlands.[2] The analysis incorporates an important role for trading and processing services required especially for long-distance (interregional) agricultural trade.[3]

The model yields both methodological and substantive insights. The substantive results provide predictions about labor allocation and population density that are different from the standard trade and core-periphery models. For example, the standard 2x2 core-periphery models predict that, in the long-run, Jamuna bridge would result in both deindustrialization and lower population density in the treatment hinterland. In contrast, in our model, population density can increase in the treatment hinterland even though the bridge leads to significant deindustrialization; deindustrialization thus does not necessarily imply backwash effect and hollowing out of the hinterland. Because of increased specialization after the bridge opening, the standard 2x2 models (both trade and core-periphery) also predict an increase in the agricultural employment in the hinterland as it enjoys comparative advantage in agriculture. In contrast, our analysis shows that the share of agricultural employment may decline even with increased specialization according to comparative advantage when agricultural trade requires local services such as collection, processing and trading.

At a methodological level, the model provides guidance for the selection of appropriate treatment and comparison areas. It is common in the analysis of the infrastructure projects to use, implicitly or explicitly, a spatial discontinuity argument to select the treatment and comparison areas; for evaluation of bridge construction this implies that the areas adjacent to the bridge are considered as the treatment. Our analysis points to an important caveat to this seemingly plausible approach; when the focus is on the intersectoral resource allocation, the strongest effects of a reduction in trade costs are felt in regions that move out of autarky as a result of the policy intervention. This implies that the areas closest to the bridge capture the main effects of a reduction in trade costs only if they were effectively cut off from the urban center in the absence of a bridge, and, more important, the effects of trade cost reduction will be spatially heterogeneous.

[2] In a 3x3 model directional geography becomes important. Baldwin et al. (2003) consider the case where there is one periphery located between two core regions. The predictions regarding the effects of infrastructure development on the periphery region are very different.

[3] The role played by trading services in the NEG models is usually limited. The intermediate inputs are not required for trading, but used in production of a good irrespective of whether it is traded or not.

To estimate the effects of Jamuna bridge, we take advantage of upazila level panel data, and use a difference-in-difference approach where the comparison areas (i.e., the second periphery in our model) come from a region which were supposed to be connected to the growth centers in the center (Dhaka city) by the proposed, but not yet constructed, Padma bridge. As we discuss in detail later, the fact that Jamuna bridge was built in 1998, while the proposed Padma is yet to be built, reflects idiosyncratic factors, and thus can reasonably be treated as quasi-experimental. We take two additional steps to tackle potential biases in the DID estimates for the Jamuna hinterland. First, we include upazila and year fixed effects in all the regressions. Second, we implement the Oaxaca-Blinder doubly robust estimator as suggested by Kline (2011), and used by Busso et al. (2013) and Moretti and Kline (2014b). A battery of falsification tests show no differences in key economic outcomes between the treatment and comparison areas during pre-bridge period when we use the doubly robust approach.

The estimates show interesting sectoral, spatial, and intertemporal patterns. In the short run, there is no significant effect on population density in the Jamuna hinterland or the core region. This is consistent with substantial costs of migration in the short-run, and allows us to interpret the estimated effects on intersectoral allocation of labor within a region as causal. We find significant labor reallocation from agriculture to services in the treatment areas in the short-run, but no perceptible effects on the employment share of manufacturing. Perhaps more interesting and important are the long-run effects of Jamuna bridge that reject the predictions from the standard trade and the core-periphery models. There are positive effects on population density and night light (luminosity) in the treatment hinterland. This rejects one of the central predictions of the core-periphery models that lower trade costs would lead to hollowing out of the treatment hinterland as people move to the core through a cumulative interaction of market access effect, cost of living effect, and interregional migration.[4] In contrast, the long-run evidence on labor allocation to manufacturing vindicates the deindustrialization effect predicted by the core-periphery models: the labor share in manufacturing declines in the treatment hinterland compared to the isolated Padma hinterland. The evidence on intersectoral labor allocation shows that the labor share of agriculture in the treatment hinterland recovers partially in the long-run, suggesting that the lack of interregional labor mobility leads to overshooting in labor reallocation from agriculture in the short run. There is a statistically significant negative effect on agricultural productivity in the

[4] The evidence shows that the increase in population density in the core region is higher compared to that in the treatment hinterland in the long run.

treatment hinterland in the short-run, but a substantial positive effect in the long-run. The short-run decline in agricultural productivity (rice yield) might seem puzzling, but can be understood in terms of labor constraint and learning externalities in technology adoption. When technology adoption involves learning externalities, the lower prices of inputs such as fertilizer due to a reduction in the trade costs may not be sufficient to induce immediate adoption of high-yielding varieties of crops. The co-movement of population density and agricultural productivity growth in the treatment hinterland in the long-run suggests that agglomeration externalities are at play in the adoption of agricultural technology.[5] The evidence from alternative samples, progressively excluding areas close to the bridge, reveals that the effects of bridge on the intersectoral labor allocation are spatially heterogeneous, with the effects in the areas close to the bridge relatively smaller. This is consistent with our theoretical analysis if the areas close to the bridge were largely integrated with the core region in the absence of the bridge (using ferry). The empirical analysis shows that the increase in the share of labor devoted to services comes primarily from agriculture in areas far from the bridge (more than 100km away sample), but the adverse effects of reallocation on the manufacturing sector (deindustrialization) are concentrated in the intermediate sample (more than 75 km away).

The rest of the paper is organized as follows. The next section sets up a general equilibrium model of three-region and three-product economy where the core is located between the two hinterlands isolated by two rivers, and derives testable predictions about the effects of a reduction in the cost of crossing the river. Section (3) discusses the background of the Jamuna bridge. We develop the empirical strategy in the next section, and discuss the data sources and construction of the variables in section (5). Section (6) is devoted to preliminary evidence on balance of observable characteristics between treatment and comparison hinterlands. The main empirical results are reported and analyzed in section (7), and the paper ends with a summary of the findings and their implications for the literature.

(2) Related Literature

The analysis in this paper is related to a large and growing literature on the effects of market integration and transport infrastructure on a variety of economic outcomes, and on the spatial

[5] Since there is deindustrialization in the treatment hinterland in the long-run, the increase in the population density cannot be accounted for by agglomeration in manufacturing. The location of any possible agglomeration effects must be in agriculture and related trading services.

organization of economic activities in both developed and developing countries. For excellent reviews of this active area of research, see the recent surveys by Donaldson (2015) and Redding and Turner (2015). For an insightful survey of the related literature on regional inequality, see Breinlich et al. (2015). There are two points emphasized by Donaldson (2015) especially relevant for our analysis: (i) the effects of reduction in trade costs due to technological change are likely to be more important for intra-country trade, and (ii) the estimates of the effects of infrastructure need to take into account both unobserved heterogeneity and general equilibrium effects. Redding and Turner (2015) underscore the difficulties in isolating the general equilibrium effects from time-varying unobserved heterogeneity. In an interesting review of place-based policies in the context of World Bank infrastructure projects, Duranton and Venables (2017) note that, resource allocation across regions within a country may be driven by absolute advantage as both labor and capital are mobile. However, when the focus is on agriculture where the main factor of production is immobile, the resource allocation across regions of a country is primarily determined by comparative advantage, as is the case in our analysis below.

Closer to our context, there has been a recent surge in interest in understanding the effects of infrastructure in developing countries; for recent surveys of the literature see Berg et al. (2016) and Donaldson (2015). Donaldson (2018) uses archival data from colonial India to show that India's railroad network reduced trade costs and interregional price gaps, increased interregional and international trade, and real income levels. Asher and Novosad (2018) find that new feeder roads do not increase agricultural production, assets or income in villages in India, but reallocates labor from agriculture to wage labor. Atkin and Donaldson (2015) find that domestic trade costs in Nigeria and Ethiopia are four to five times larger than in USA, and the passthrough of international prices to the domestic prices are lower in remote locations. Banerjee et al.(2012) analyze the effects of access to transport infrastructure on economic growth in China; Emran and Hou (2013) provide evidence that better access to domestic and international markets increase household consumption in rural China, and that there is complementarity between domestic and international market access; Faber (2014) finds that transport network connection had adverse effects on industrial growth in peripheral counties in China; and Baum-Snow et al. (2017) study the effects of roads and rainway on urban form in China, and provide evidence that provide evidence that radial highways decentralize service sector activity, radial railroads decentralize industrial activity, and ring roads decentralize both. Duranton (2015) shows that, in Colombia, road distance between cities is a major impediment to trade. In the context of Mexico, Blankespoor et al. (2017) find evidence of significant and positive causal effects of improved domestic accessibility on employment and specialization.[6] Bird and Straub (2014) study the effects of rapid road network expansion between 1960 and 2000 in Barzil using a historical natural experiment and show that proximity to the newly constructed radial road network increases population, GDP and GDP per capita.

Using nightlights data as an indicator of economic activity, Storeygard (2016) provides an estimate of the elasticity of city economic activity to transport costs of -0.25 for 15 sub-Saharan African countries. Gollin and Rogerson (2014) analyze the implications of exogeneous productivity change for the effects of transport cost reduction on subsistence agriculture in the context of Uganda.[7] Ali et al. (2016) show that lower transport costs induce farmers adopt better farming techniques. Using survey data from Nepal, Fafchamps and Shilpi (2005) show that areas close to cities are more diversified and more market-oriented activities, and Fafchamps and Shilpi (2003) find evidence of spatial division of labor: the nonfarm activities are concentrated around cities, while agriculture dominates in villages located further away. Emran and Shilpi (2012) find evidence of an inverted-U relation between crop diversification and access to markets in Nepal.

Most of the available literature, as discussed above, focuses on the road and railway infrastructure. Tompsett (2013) analyzes the effects of bridges over the Ohio and Mississippi rivers on population density and value of agricultural land. The evidence suggests positive effects on both population density and value of agricultural land. In the context of Bangladesh, Mahmud and Sawada (2014) provide preliminary evidence on labor market effects of Jamuna bridge, the focus of our analysis. The data used in their analysis cover only two districts adjacent to the Jamuna bridge (Tangail and Sirajgonj), and thus likely to miss much of effects of the bridge construction on labor reallocation as discussed below.[8]

[6] They also find that employment is stimulated by lower transport costs to the U.S. border, but harmed by lower transport costs to ports.

[7] In contrast, agricultural productivity responds endogeneously to the reduction of transport costs in the long run in our analysis.

[8] The central (sadar) Upazila in Tangail district is 33 km from the Jamuna bridge, and the central upazila in Sirajgonj district is 30 km from the Jamuna bridge. The distances are estimated using google map.

(2) Trade and Transport Costs in A Model of Three-Region and Three-product Economy

We develop a model with the following features: (1) there are three regions separated by two rivers, and the industrial core is located in between the two rivers, (2) three goods: agriculture, manufacturing, and services, (3) technological change in both agriculture and manufacturing through agglomeration. The basic set up of the model is described below.

Geography

We consider the geography where all possible locations are ordered along a line between the interval $[H_1, K_1]$ (Figure 1). The line is divided into three segments by the presence of two rivers. The first river (R_H) is located closer to H_1 and the riverbanks are denoted as H_0 and J_{0H}. The second river (R_K) is located closer to K_1 and its banks are denoted as J_{0K} and K_0. As shown in Figure 1, the presence of rivers defines three regions: $H = [H_1, H_0]$; $J = [J_{0H}, J_{0K}]$; and $K = [K_0, K_1]$. There are continuum of locations in each of the regions. Each location in region H is indexed by h, where h is the distance from riverbank H_0. Similarly each location in region J is indexed by j which shows the distance from river bank J_{0H} , and in region K by k which shows the distance from riverbank K_0. In the absence of bridges, each river is crossed by using ferry. Two rivers are identical in width and water flow leading to identical costs of ferry. The cost of ferry is ($F_H = F_K = F$). Shipping of a good between two locations across any of the rivers involves an iceberg cost $e^{\tau d+F}$ where τ is a positive constant and d is the distance between the locations. Each location i is endowed with $T_i = T > 0, : i \in \{H, J, K\}$ units of land. This assumption rules out endowment heterogeneity at the micro (location) level, but total land endowments may differ across regions H, J, and K depending on their respective lengths. There is a mass of N workers in this economy each supplying 1 unit of labor inelastically. Labor is immobile in the short-run, mobile across locations within each region in the medium run, but mobile across regions in the long run. Regions H and K are identical to each other with one exception that they are located on either sides of region J.

Production

Each region can produce two goods: manufacturing (m), agriculture (x), and two different types of services (s), one consumed by individuals and the other used in production. Production services include processing, trading and logistic services.[9] While regions can trade in agriculture

[9] While these services are important for manufacturing, they are particularly relevant for agricultural trade. Most

and manufacturing goods, services are non-traded. Manufacturing and agriculture are produced by combining labor, land and production services whereas production of both types of services requires only labor. Production services consist of processing, transporting and trading of goods which may be more important for bulky agricultural goods. Total factor productivity for each product in a given region may depend on regional characteristics such as climate, the extent of technology adoption in agriculture, and employment density for manufacturing.

The simple CRS production technologies for agriculture and manufacturing and three types of services are described as:

$$\begin{aligned} Q_{xi} &= A_{xi} T_{xi}^{\beta} S_{xi}^{1-\beta-\phi_q} L_{xi}^{\phi_q}; \qquad Q_{sxi} = A_{xsi} L_{xsi} \\ Q_{mi} &= A_{mi} T_{mi}^{\beta} S_{mi}^{1-\beta-\phi_q} L_{mi}^{\phi_q}; \quad Q_{smi} = A_{msi} L_{msi} \\ & Q_{si} = A_{si} L_{si}; \qquad i \in [H_1, K_1] \end{aligned}$$

Where Q_{si} is consumer services and Q_{sxi} and Q_{smi} are production services for agriculture and manufacturing respectively. Total factor productivity in agriculture and manufacturing in a location i depend on population density, and can be described as:

$$A_{xi} = \bar{A}_{xi} n_i^{\alpha_x}; \; A_{mi} = \bar{A}_{mi} n_i^{\alpha_m}; \quad \bar{A}_{xh} = \bar{A}_{xk} > \bar{A}_{xj}; \quad \bar{A}_{mh} = \bar{A}_{mk} < \bar{A}_{mj}$$

where $\bar{A}_{xi}$ and $\bar{A}_{mi}$ are region specific productivity parameters (first nature geography) and $n_i = \frac{N_i}{T_i}$ is population density and $0 < \alpha_x, \alpha_m < 1 - \beta$. This specification of factor productivity is a standard way of capturing agglomeration externalities in the manufacturing sector. Agglomeration economy in manufacturing arises from closer input-output relationship, thick labor market and learning externalities. A prominent theme in the agricultural economics literature is that technology adoption in agriculture is subject to important network and learning externalities. The network externality may arise, for example, from the need to build a marketing infrastructure for trading of inputs and outputs (Besley and Case (1993); Emran and Shilpi (2002)). Moreover, farmers may care about other's adoption decisions if early adopters teach late adopters about the viability of the technology when returns to adoption are uncertain (Beasley and Case (1993)). Consequently, adoption of new technology in agriculture is often modeled to depend on existing

agricultural production is done by small family farms and exporting it to other regions involves an apparatus of traders and processors for collection, sorting, processing and shipping.

stock of knowledge and network, and population density is a good proxy for both of these factors. Unlike manufacturing and agriculture, factor productivity in services is not affected by population density, and is assumed to be the same across regions. We assume that region J has comparative advantage in the production of manufacturing (m) and region H (and K) in the production of agriculture (x).

Consumption

Consumer in each region has identical preference over consumption of three goods: agriculture, manufacturing and consumer services.

$$U = C_m^{\gamma} C_x^{\delta} C_s^{1-\gamma-\delta}$$

The utility maximization by a representative consumer given prices of goods and services results in following indirect utility function:

$$V_i = \frac{\gamma^{\gamma}\delta^{\delta}(1-\gamma-\delta)^{1-\gamma-\delta} y_i}{P_{mi}^{\gamma} P_{xi}^{\delta} P_{si}^{1-\gamma-\delta}}$$

where y_i is the income of the representative consumer in location i. To focus better on the role of transport costs and technological change in agriculture and to simplify notation and algebra, we adopt the following assumptions:

(i) *Technology*: There is no heterogeneity in the production technology of services across regions ($A_{si} = A_s$, $A_{xsi} = A_{xs}$, $A_{msi} = A_{ms}$) and in the location-specific factor productivity in agriculture and manufacturing ($\bar{A}_{xi}$ and $\bar{A}_{mi}$) within a region for traded goods ($\bar{A}_{xh} = \bar{A}_{xh'}$ $\forall h, h' \in H$ and so on). The location specific productivity of manufacturing and agriculture are different across regions. Specifically we assume that region H and K have higher location specific productivity in agriculture and region J has in manufacturing ($\bar{A}_{xh} > \bar{A}_{xj}$ and $\bar{A}_{mj} > \bar{A}_{mh}$ $\forall h \in H;\ j \in J$). Though there is no intra-regional heterogeneity in the location specific productivity, the ex-post total factor productivity for the same good can be different within a region depending on the strength of agglomeration externality as captured by population density of each location. For simplicity of characterization of equilibrium, we assume $\alpha_x = \alpha_m = \alpha$, though we relax this assumption later.

(ii) *Transport Costs*: The transport cost between two locations depends only on the distance between them and whether they are on the opposite sides of the river ($e^{\tau d + F}$ if they are in two different regions; and $e^{\tau d}$ if within the same region where τ is a positive constant and d is the distance between the locations). This assumption implies that transport costs are not product specific, though this assumption can be relaxed at the cost of adding more notations. Note that if F is prohibitively large, it can preclude any inter-regional trade leading to autarky. On the other hand, if F and τ are very small, then all locations across rivers will trade with each other resulting in a fully integrated economy even in the absence of a bridge. We assume that the transport cost τ and ferry cost F are in the intermediate range such that each region contains integrated and isolated subregions. This assumption allows us to describe local and regional level population and employment configuration by focusing on any pair of trading subregions since regions H and K are identical at the initial equilibrium.

(iii) *Preference:* We assume that $\gamma = \delta$ which implies that income shares of agriculture and manufacturing in the consumption bundles are equal. This means that demand heterogeneity across agriculture and manufacturing does not play any role in our analysis, and simplifies the algebra substantially.

(2.2) Pre-Bridge Equilibrium

A competitive equilibrium in this economy consists of a set of prices (goods and factors) given endowments (land and labor) and inherent productivity differences such that (i) labor market clears locally, regionally and at the country level; (ii) land market clears at the local level, land being the immobile factor of production; (iii) equalization of utility across locations among which workers are mobile (within region in the medium run and at the national level in the long run). The ferry and transport costs are in the intermediate range allowing both integrated and isolated sub region within each region. The integrated sub-region in H is denoted as $H^{\blacktriangle}$ and the isolated as $H^{\triangledown}$ implying that $H = H^{\blacktriangle} + H^{\triangledown}$. Since the core region J can trade with both H and K hinterlands, the isolated region $J^{\triangledown}$ falls in the middle, while the isolated regions $H^{\triangledown}$ and $K^{\triangledown}$ are situated at the other end away from the bridge. We denote the integrated sub-region in J that trades with $H^{\blacktriangle}$ and $K^{\blacktriangle}$ by $J_H^{\blacktriangle}$ and $J_K^{\blacktriangle}$ respectively.

Equilibrium in the Isolated Sub-regions

We start with characterizing the equilibrium under autarky where regions do not trade with each other (e.g. $H^{\triangledown}$). By assumptions, there is no heterogeneity in the production technology for the same good within the isolated sub-region, and for each good, production technology is characterized by CRS. Markets are competitive but trading involves positive transport costs. These assumptions deliver the following results: (i) the spatial impossibility theorem (Starret (1978)) that there is no trade within the sub-region and hence each location is characterized by autarky and produces agriculture, manufacturing, and production and consumer services, (ii) population density does not vary across locations within an isolated subregion, (iii) the equilibrium relative price of manufacturing and agriculture does not vary across locations within the isolated sub-region, but relative price of manufacturing is higher in the isolated sub-regions in the hinterlands, i.e., in $H^{\triangledown}$ and $K^{\triangledown}$compared to $J^{\triangledown}$, reflecting lower productivity of manufacturing in the hinterlands . The labor share employed in manufacturing does not vary across different isolated sub-regions ($H^{\triangledown}$, $K^{\triangledown}$, $J^{\triangledown}$) , as the real wages do not vary across subregions in autarky. This provides us a clean benchmark for understanding sectoral reallocation of labor between manufacturing and agriculture in response to bridge construction.

Equilibrium in the Integrated Sub-regions

Assuming ferry and transport costs fall in an intermediate range, subregion $H^{\blacktriangle}$ specializes in agriculture and $J_H^{\blacktriangle}$ in manufacturing. The effects of market integration on labor allocation in this model are due to specialization of locations (and sub-regions) according to comparative advantage. In a location $h \in H^{\blacktriangle}$, $\frac{(1-2\gamma)}{1-2\beta\gamma}$ proportion of total population N_h goes to the production of consumer services, but the rest to agriculture. Denoting variables at riverbank with a subscript 0, price of m at any location $h \in H^{\blacktriangle}$ is $P_{mh} = P_{mj0}e^{F_H+\tau h}$ and price of x is $P_{xh} = P_{xh0}e^{-\tau h}$, where h is the distance between the riverbank H_0 and location h in the integrated subregion. The relative price of agriculture to manufacturing $\dfrac{P_{xh}}{P_{mh}}(= \dfrac{P_{xh0}}{P_{mh0}}e^{-F-2\tau h})$ decreases as one moves farther away from the riverbank and into the interior of $H^{\blacktriangle}$. Since hinterland K is also separated from the center by an identical river and connected by the same ferry service, the trading subregions $K^{\blacktriangle}$ and $J_K^{\blacktriangle}$ are characterized by identical equilibrium conditions. The equilibrium in this case displays the following patterns: (i) population density in an integrated sub-region decreases with an increase in distance from the river bank and the slope of population density curve with respect to distance from the riven bank is larger in absolute value if the agglomeration effect is stronger; (ii) integrated subregions in the hinterlands, i.e., $H^{\blacktriangle}$ and $K^{\blacktriangle}$specialize in agriculture and do not produce manufacturing (goods and productions services), and integrated subregions in the core, i.e., $J_H^{\blacktriangle}$ and $J_K^{\blacktriangle}$ specialize in manufacturing and do not engage in agriculture; (ii) population density in the integrated core $J_H^{\blacktriangle}$ ($J_K^{\blacktriangle}$) relative to that in the integrated hinterland $H^{\blacktriangle}$ ($K^{\blacktriangle}$)

increase with a higher productivity gap in manufacturing, ceteris paribus. The converse also holds, population density in integrated parts of the hinterlands relative to the integrated subregions of the core increases when the productivity gap in agriculture is higher.

Discussion

We omit the formal proof for the above results (please see online appendix) and provide some intuitions here. Using the first order conditions along with equalization of worker's utility across regions, total population in $h \in H^{\blacktriangle}$ is:

$$N_h = e^{-\frac{\tau}{\beta-\alpha}h} N_{h0}$$

where N_{h0} is the population at river bank H_0 and h is the distance from riverbank. Total population in a location $h \in H^{\blacktriangle}$ not only falls with an increase in distance from riverbank, but also declines at a faster rate with an increase in agglomeration externality (α) in agriculture. Since each location is endowed with the same amount of land, this also implies that population density declines at a faster rate if agglomeration externality in agriculture is higher.

It is shown in online appendix that wages are equalized across regions due to labor mobility, and that goods market equilibrium implies equality of total employment in the integrated subregions$N_H^{\blacktriangle}$ and $N_{JH}^{\blacktriangle}$. As an equal number of people live in each integrated subregion, population density depends on its length. Note that the relative price of import at any location $h \in H^{\blacktriangle}$ is $\frac{P_{mh}}{P_{xh}} = \frac{P_{mj0}}{P_{xh0}} e^{F+2\tau h}$. Relative price of importable of a region (manufacturing for region $H^{\blacktriangle}$) increases as one moves farther interior from the riverbank. Using the first order conditions along with labor allocation across space, the equilibrium price ratio is determined as:

$$\frac{P_{mj0}}{P_{xh0}} = \frac{\phi_x^{1-\beta} \bar{a}_{xh}}{\phi_m^{1-\beta} \bar{a}_{mj}} [\frac{1 - e^{-\frac{\tau}{\beta-\alpha} H^{\blacktriangle}}}{1 - e^{-\frac{\tau}{\beta-\alpha} J^{\blacktriangle}}}]^{\beta-\alpha}$$

where $\bar{a}_{qi} = \bar{A}_{qi} [\frac{A_{qsi}(1-\beta-\phi_q)}{\phi_q}]^{1-\beta-\phi_q}$ and $q = x, m, i = h, j$.The border of the trading zone is determined by the arbitrage condition that at the border, the price ratio under trade should be equal to the autarky price ratio. The border of the trading zone and hence the lengths of integrated subregions are determined by the following two equations (in log form):[10]

$$2\tau H^{\blacktriangle} + \beta[\ln(1 - e^{-\frac{\tau}{\beta-\alpha}H^{\blacktriangle}}) - \ln(1 - e^{-\frac{\tau}{\beta-\alpha}J^{\blacktriangle}})] \quad = \quad \ln \bar{a}_{mj} - \ln \bar{a}_{mh} - F \qquad (1)$$

$$2\tau J_H^{\blacktriangle} + \beta[\ln(1 - e^{-\frac{\tau}{\beta-\alpha}J^{\blacktriangle}}) - \ln(1 - e^{-\frac{\tau}{\beta-\alpha}H^{\blacktriangle}})] \quad = \quad \ln \bar{a}_{xh} - \ln \bar{a}_{xj} - F \qquad (2)$$

Note that $J_H^{\blacktriangle} = H^{\blacktriangle}$ only if $(\ln \bar{a}_{mj} - \ln \bar{a}_{mh}) = (\ln \bar{a}_{xh} - \ln \bar{a}_{xj})$. This is in contrast to the equal population distribution between the two trading partners which is determined by preference parameters alone. Thus despite symmetry in preference for agriculture and manufacturing (i.e., $\gamma = \delta$), population density in the integrated subregions in the opposite sides of the river R_H could be different depending on productivity differences for these products. As shown in the appendix B, an increase in $(\ln \bar{a}_{mj} - \ln \bar{a}_{mh})$ increases both $J_H^{\blacktriangle}$ and $H^{\blacktriangle}$, but the increase in $H^{\blacktriangle}$is larger. Given that half of total population in the trading subregions is in $H^{\blacktriangle}$, this implies a higher density of population in $J_H^{\blacktriangle}$ than $H^{\blacktriangle}$. Note also that for trade to be feasible between these two regions, F has to be less than $\hat{F}$, where $\hat{F} = \min\{(\ln \bar{a}_{mj} - \ln \bar{a}_{mh}), (\ln \bar{a}_{xh} - \ln \bar{a}_{xj})\}$. An increase in transport cost τ decreases both $J_H^{\blacktriangle}$ and $H^{\blacktriangle}$. Assuming $(\ln \bar{a}_{mj} - \ln \bar{a}_{mh}) > (\ln \bar{a}_{xh} - \ln \bar{a}_{xj})$, define $\hat{\tau}$ such that $H^{\blacktriangle} = H$ in equation (1). For $\tau \leq \hat{\tau}$, there will be no subregion that is isolated. The equilibrium characterized here thus assumes $F << \hat{F}$ and $\tau >> \hat{\tau}$.

Economy-wide Equilibrium and Worker's Indirect Utility

Labor mobility across regions links the integrated and isolated subregions throughout the country in the long run. The spatial equilibrium in this economy displays the following characteristics: (i) within each region, population density in integrated subregion is higher than that in the isolated subregion, (ii) all three regions produce all five different goods and services, (iii) regions H and K have more employment in agriculture and region J has more manufacturing employment compared with the autarky equilibrium.

The maximized utility ($\overline{v}$) is determined from the economy-wide labor market clearing condition as:

$$N\overline{v}^{\frac{1}{2\gamma(\beta-\alpha)}} = T\sum\{n_{vI}^{\triangledown}[\frac{\beta-\alpha}{\tau}(e^{\frac{\tau}{\beta-\alpha}I^{\blacktriangle}} - 1) + I - I^{\blacktriangle}];\ I \in \{J, H, K\}; I^{\blacktriangle} \in \{J_H^{\blacktriangle}, H^{\blacktriangle}, K^{\blacktriangle}, J_K^{\blacktriangle}\} \quad (3)$$

where $n_{vI}^{\triangledown} = [\frac{(1-2\beta\gamma)}{2\gamma}]^{\frac{\beta}{(\beta-\alpha)}} \phi_x^{\frac{1-\beta}{2(\beta-\alpha)}} \phi_m^{\frac{1-\beta}{2(\beta-\alpha)}} (\bar{a}_{xI})^{\frac{1}{2(\beta-\alpha)}} (\bar{a}_{mI})^{\frac{1}{2(\beta-\alpha)}} A_s^{\frac{1-2\gamma}{2\gamma(\beta-\alpha)}}$ and N is the total endow-

[10] Derivations of these equations are described in appendix A.

ment of labor in this three-region economy. $n_i^{\triangledown} = n_{vI}^{\triangledown}\overline{v}^{-\frac{1}{2\gamma(\beta-\alpha)}}$ is the population density at $i \in I^{\triangledown}$ in the isolated subregion. Population density at any point $i \in I^{\blacktriangle}$ is equal to $n_i^{\blacktriangle} = n_{vI}^{\triangledown}\overline{v}^{-\frac{1}{2\gamma(\beta-\alpha)}}$ $e^{\frac{\tau}{\beta-\alpha}[I^{\blacktriangle}-i]}$ and thus higher than what it would have been under autarky, as $e^{\frac{\tau}{\beta-\alpha}[I^{\blacktriangle}-i]} \geqq 1$. The presence of agglomeration externality implies higher density at a given location since $\beta - \alpha < \beta$. Equations 1-3 jointly determine the distribution of population, productivity and trading status of locations in this model in the long run. Sub-regions $H^{\blacktriangle}$and $K^{\blacktriangle}$ specialize in x and $J_H^{\blacktriangle}$ and $J_K^{\blacktriangle}$ specialize in m whereas isolated subregions in all regions produce all five goods and services. As a result, employment in H and K is tilted towards agriculture and in J toward manufacturing. Employment composition in the region H can be described as:

$$N_{xH} = \frac{\phi_x\gamma[2N_H^{\blacktriangle} + N_H^{\triangledown}]}{1-2\beta\gamma}; N_{mH} = \frac{\gamma\phi_m N_H^{\triangledown}}{1-2\beta\gamma}; N_{sH} = \frac{(1-2\gamma)\overline{N}_H}{1-2\beta\gamma} \quad (4)$$

$$N_{xsH} = \frac{\gamma(1-\beta-\phi_x)[2N_H^{\blacktriangle} + N_H^{\triangledown}]}{1-2\beta\gamma}; N_{msH} = \frac{\gamma(1-\beta-\phi_m)N_H^{\triangledown}}{1-2\beta\gamma} \quad (5)$$

where $N_H^{\blacktriangle} = \int_0^{H^{\blacktriangle}} n_h^{\blacktriangle} dh$ and $N_H^{\triangledown} = n_i^{\triangledown}(H - H^{\blacktriangle})$ are total population in the integrated and isolated subregions respectively. The blue shaded curve in Figure 2 describes the equilibrium distribution of population density in region H before construction of bridge. Population density is highest at the riverbank and decreases steadily as one moves toward the boundary point of $H^{\blacktriangle}$. Between H_1 and $H^{\blacktriangle}$, density does not vary with distance as this comprises the isolated locations. Since agglomeration externalities follow population density, productivity in agriculture in H displays the same pattern.

(2.3) The Effects of Bridge Over the River R_H

We consider the case where a bridge is constructed only over the river R_H (corresponds to Jamuna river in our empirical analysis) that separates regions H and J. Construction of the bridge reduces the cost of crossing the river between H and J but does not change the ferry cost between J and K ($F_H < F_K = F$). We consider two different scenarios regarding the impacts of construction of bridge depending on labor mobility: (i) in the short-run, labor is immobile, and (ii) in the long-run when labor is mobile both across and within regions. In the appendix, we analyze effects of bridge in the medium run when labor is mobile within region but not across regions.

The Short-run Effects: Labor Immobile

Absence of labor mobility means that the effects of bridge can be analyzed by focusing on regions H and J separately. We focus on region H first. A lower F_h decreases the price of manufacturing goods imported from J at location h, P_{mh} , but has no direct impact on the price of agriculture P_{xh}, resulting in an increase in the relative price of exportable for a location $h \in H_B^{\blacktriangle}$, where subscript B refers to variables measured in the periods after bridge construction. The change in relative price induces intersectoral labor reallocation as more locations in H switch from autarky to trading and specialize in agriculture, thus $H^{\blacktriangle} \subset H_B^{\blacktriangle}$. Proposition 1 summarizes the effects of bridge in the short-term when labor is immobile even within a region.

Proposition 1: Assume that the isolated sub-region in the core after bridge construction is a non-null set, i.e., $J_B^{\triangledown} > 0$ *. In the short run when labor is immobile, a decrease in the cost of river crossing due to construction of a bridge between regions H and J leads to the following (denoting post-bridge variables with a subscript B):*

(i) a decrease in employment in manufacturing ("de-industrialization") in region H and in agriculture in J;

(ii) an increase in employment share of services in regions H and J if production services are used only for inter-regional trade;

(iii) a decrease in employment share of agriculture in region H if production services are used only for inter-regional trade and $\frac{(1-\beta)}{2} > \phi_x$;

(iv) employment reallocation effect is strongest in locations that switch from autarky to trading as a result of bridge ($h \in [H^{\blacktriangle}, H_B^{\blacktriangle}]$)*; and*

(v) no impact on population density or employment density in subregions and regions ($J_K^{\blacktriangle}, K^{\blacktriangle}, K^{\triangledown}$)*, not directly connected by bridge.*

The proof of this proposition is provided in online appendix and we briefly discuss the intuitions behind it here. In the short-run, labor is immobile within and across regions. Note that $\frac{P_{mh}}{P_{xh}} = \frac{P_{mj0}}{P_{xh0}} e^{F+2\tau h}$ where $\frac{P_{mj0}}{P_{xh0}}$ stays at the pre-bridge equilibrium due to labor immobility. We show in the appendix that $\frac{\partial H^{\blacktriangle}}{\partial F_H}|_{SR} = -\frac{1}{2\tau} = \frac{\partial J^{\blacktriangle}}{\partial F_H}|_{SR} < 0$. In other words, bridge leads to an *an expansion in the integrated sub-regions, i.e.,* $H_B^{\blacktriangle} \supset H^{\blacktriangle}$*, and* $J_{HB}^{\blacktriangle} \supset J_H^{\blacktriangle}$*, and a shrinkage of the isolated subregion in both the core and periphery regions, i.e.,* $H_B^{\triangledown} \subset H^{\triangledown}$ *and* $J_B^{\triangledown} \subset J^{\triangledown}$. Because of the extension of the trading subregion, total employment and hence population in the integrated subregion increases even without labor movement. The newly integrated subregion specializes in agriculture in H and in manufacturing in J, leading to the prediction in proposition 1(i).

Note that the share of consumption services in total employment does not change due to a decrease in F_H as a constant proportion of income is spent on this which is nontaradable and produced under CRS. If production related services are required regardless of whether a location is engaged in trade or not, then the impact of bridge on services share is ambiguous and depends on whether importables or exportables use production services more intensively. It has a positive impact on services share in region H if $\phi_x < \phi_m$, has no impact if $\phi_x = \phi_m$ and negative impact if $\phi_x > \phi_m$. Suppose production related service is necessary only when a location is engaged in inter-regional trade. This means $\phi_x = (1-\beta)$ under autarky and $\phi_x < (1-\beta)$ under inter-regional trade. We show in the appendix that $\frac{\partial}{\partial F_H}(\frac{N_{xh}}{N_h}) = \frac{\gamma}{(1-2\beta\gamma)}[2\phi_x - (1-\beta)] < 0$ if $\frac{(1-\beta)}{2} > \phi_x$. Employment shares in areas that were either integrated before the bridge or remained isolated after the bridge are not affected by a reduction in F_H. Finally, because the cost of crossing the river between J and K are unaffected, and $J^{\triangledown}$ is non-null by assumption, employment composition and population distribution in region K and subregion $J_K^{\blacktriangle}$ remain unaffected by a reduction in F_H.

In the short run analysis above, we assumed the presence of an autarkic region in J after the reduction in F_H. In the event that the length of the zone in J that trades with H encroaches on the zone that trades with K, it is easy to see that trading zone in K will shrink leading to a reduction in agricultural and services employment and an increase in manufacturing employment in K even in the short run because of expansion of isolated sub-region.

The Long-run Effects: Labor mobile between regions

In the long run, labor is mobile across regions, and the utility of workers in integrated subregions directly connected by bridge increases with a reduction in F_H.

Proposition 2: In the long run, a decrease in the cost of river crossing due to the construction of a bridge between regions H and J leads to the following effects:

(i) a further extension of $H_B^{\blacktriangle}$ if $H^{\blacktriangle} > J^{\blacktriangle}$ in initial equilibrium and vice versa;

(ii) reduces the population density in the region that did not receive the bridge (region K) and increases the population density in both the connected integrated regions (H, J_H), more so in the center if agglomeration externality in manufacturing is larger;

(iii) Integrated areas (new and old) experience higher productivity in their exportables due to technological externality;

(iii) The effects on employment specialization is more pronounced in the long run compared

with short-run due to population mobility and positive productivity effects and

(iv) similar to short-run effects, employment effects are strongest at the extensive margin of pre-bridge integrated subregion.

Proof: Omitted. Please see online Appendix.

The impacts of bridge on population density is shown in Figure 2. The post bridge curves are shaded in green for short-run and black for long-run effects. In the short-run, only the border of integrated region is shifted outward. The density curve for H shifts upward in the long-run due to an influx of people from the other hinterland (K). This results in the further expansion of $H^{\blacktriangle}$ and an increase in the density, productivity and employment specialization.

(2.4) Discussion

The model used above is a static set-up and assumes away migration costs. We show in the online appendix that with staggered migration and time lag in realization of agglomeration externality, the adjustment from short to long run can be viewed as a staggered process as well. The presence of productivity effects in agriculture and manufacturing provides additional sources of deviations between short and long term effects beyond mobility of workers. While agglomeration in this model is driven by population density, an alternative model can be developed where technology adoption due to lower input prices following the bridge construction drives population movement and thus acts as the primary source of deviation between short-term and longer term effects. Since price adjustments takes place with shorter time lag compared to population movements across regions, we would expect to observe an increase in productivity in the short-run if the lower prices of inputs such as fertilizer and pesticides are the primary driving forces behind the technological change in agriculture. In contrast, if lower input prices are not sufficient for technology adoption, but adoption depends on learning and information externalities associated with density, then we expect to see the agricultural productivity and population density to co-move in the long-run following the opening of the bridge. In practice, it is likely that both lower input prices and agglomeration economies operate simultaneously reinforcing each other.

The $3X3$ model developed here can be utilized to contrast predictions from alternative $2X2$ (two regions and two products: manufacturing and agriculture) model. Predictions from classical trade model can be derived by setting $\alpha_x = \alpha_m = \alpha = 0$ and $K = 0$. If $H^{\triangledown}, J_H^{\triangledown} > 0$, then this classical model predicts an increase in agriculture's share in employment in H and manufacturing's share in J. On the other hand, if both regions were fully integrated before bridge ($H^{\triangledown} = J^{\triangledown}_{H} = 0$), then opening of bridge has no impact on employment composition or population density though it improves welfare (increases $\bar{v}$). For predictions from a simple core-periphery model, we set $H^{\triangledown}, J^{\triangledown}_{H} > 0; K^{\triangledown} = K = 0$ and $\alpha_x = 0, \alpha_m > 0$. In other words, agglomeration externality is present only in manufacturing and inter-regional trade was not feasible before bridge construction. This core-periphery set up predicts an increase in manufacturing share and population density in J and a decrease in the same in region H. Having the second hinterland in the model allows population density in H to increase in contrast with classical and core-periphery models. While having a non-traded consumption services does not change composition of employment due to homothetic preference, presence of production service that are needed in case of inter-regional trade can actually lead to a decline in agriculture in region H even though it specializes in agriculture.

(3) Jamuna Bridge: Background and the Context

To test the predictions in propositions 1-3, we study the construction of a critical bridge in Bangladesh called Jamuna bridge. Jamuna bridge is a particularly interesting case study for a number of reasons. Bangladesh, a riverine delta, is sliced into three separate regions by two major rivers in Asia: the Ganges (locally known as Padma) and Brahmaputra (locally known as Jamuna) (please see map 1 in online appendix). These two rivers effectively cut-off the North-west and Southern regions of the country from the growth centers in the middle where capital city Dhaka is located. The 4.8 kilometer long Jamuna bridge connected the poor North-west region (about 26 million and 24.5 percent of country's total population in 1991) to the main growth centers (Dhaka city). The bridge has 4 vehicle traffic lanes, and a railway line. The actual cost of building the bridge was about $985 million. Three donors (World Bank, JICA and Asian Development Bank) each contributed roughly about $200 million, and rest was borne by the country itself.

The bridge had significant impact on travel time and cost. Before the opening of the bridge, crossing the river by ferries took more than 3 hours, and during heavy traffic periods (e.g. Eid festivities), the average waiting time at the ferry ran as high as 36 hours (Staff Appraisal report, World Bank).[11] River crossing after the opening of the bridge in mid-1998 takes less than an hour (including the waiting time). According to government estimates, the bridge cut the average

[11] The estimate is for 1993.

travel time by 4 hours during the normal traffic time and reduced the freight costs by a half. Travel time by truck between Bogra town in the Jamuna hinterland and the capital city Dhaka was reduced from 20 hours to 6 hours.[12] The bridge thus removed a critical bottleneck in the transport connection and led to a very substantial reduction in transport time and costs. Such a large and discontinuous reduction in transport costs for a significant size of population provides an excellent opportunity to study the effects of trade costs on spatial organization of activities which may not be detectable when the change in transport cost is small and local.

Before the construction of the Jamuna bridge, the North-west region had been the poorest in the country with poverty incidence of 61 percent in 1995/96 compared with 40 percent in the main growth centers around the capital city Dhaka. Prior to bridge construction, about 81 percent of labor force in the North-west region were engaged in agriculture compared with 66 percent in the center. The bridge thus offers an excellent set-up to examine the possibility of backwash effects of market integration and the channels through which spatial organization of economic activities are affected in a predominantly agrarian poor region, as is the case in much of developing world.

(4) Empirical Issues and Strategy

To estimate the effects of bridge in the short and long run, we compare the subdistricts in the treatment hinterland (region H in the model) and those in core (region J) with the subdistricts in the Padma hinterland not connected by the Jamuna bridge (region K). We use the following difference in difference (DID) specification:

$$Y_{ijt} = b_0 + b_1 T * Yr + b_2 C * Yr + b_3 Z_{ij0} + +b_4 T + b_5 C + \theta_i + \mu_t + \varepsilon_{ijt} \tag{6}$$

where Y_{ijt} is the outcome variable j in subdistrict i and period t. T is a dummy variable which takes a value of unity if a subdistrict is located in region H and 0 otherwise. C is a dummy variable that takes on the value of unity if a subdistrict is located in the core J, and zero otherwise. Yr is a dummy that takes the value of unity if the year is after the bridge opening in 1998 and zero otherwise. Z_{ij0} is a vector of pre-bridge characteristics and Z_{ijt} is a vector of contemporaneous and exogenous characteristics (e.g. rainfall). θ_i captures the time-invariant sub-district level factors, and μ_t the common macro shocks in a year. In estimating equation (6), we use both

[12] It took much longer for trucks transporting goods to cross the river by ferry because buses carrying people had priority in getting access to the ferry boats. As a result, trucks had to wait much longer at ferry gate.

upazila fixed effect and a time (year) fixed effect. In this formulation, the estimates of b_1 and b_2 are the effects of bridge on the treatment hinterland (H) and the core region (J) relative to the comparison hinterland (K).

There are two types of dependent (or outcome) variables of interest. The dependent variables in levels such as population density, average luminosity of night lights and yield are all expressed in natural logs. Our second set of dependent variables are expressed as shares of the relevant total such as share of workers employed in agriculture, industry and services. We have data for three periods for the share variables and have longer time dimension for the data on night lights (1992-2012) and yield (1988-2013). The availability of longer time dimension allows us to estimate the effects of bridge on night lights and yield using growth rates as additional outcome variables.

In addition to the fixed effect DID (DID-FE) estimates using OLS for equation (6), we use two approaches developed by Busso et al. (2013), Moretti and Kline (2014b) and Kline (2011) to reduce potential biases in the estimates. To improve the comparability of the control and treatment subdistricts, we undertake two weighting schemes using the pre-bridge characteristics. The first approach uses propensity scores from a logit model of the probability of being included in the treatment area using the pre-bridge characteristics. The predicted probabilities are used to define weight for each observation (subdistrict) in the control subset. The regressions also directly control for the pre-bridge characteristics, and thus the approach is similar to the doubly-robust estimators proposed by Robins et al. (1994) and Wooldridge (2007). We call this approach LWRA (logit weighted and regression adjusted) estimator. The second estimator developed by Kline (2011) and Moretti and Kline (2014b) uses the weights generated from the Oaxaca-Blinder approach as suggested by Kline (2011). The variables used for the Oaxaca-Blinder weights are the same as the ones used in computing logit probability weights. As discussed in Kline (2011), the Oaxaca-Blinder estimator is also doubly robust. To emphasize its doubly robust property, We call this approach OBDR (Oaxaca-Blinder doubly-robust) estimator. When using the doubly robust estimators, the estimation sample is trimmed by dropping 5% of the comparison sample with the lowest predicted propensity score to improve comparability.

Our vector of pre-bridge covariates (Z_{ij0}) includes a set of variables measured in 1990/1991. They are log of population, log of distance (crow-fly) to bridge (to Jamuna for treatment, and to the proposed Padma for control areas, minimum of two for those in the core), and suitability of land for rice production.[13] We control for the crow-fly distance to ensure that the estimated effects are not distorted by comparison of locations at different distances from the bridge. Following the suggestion of Henderson, Storeygard and Weil (2012), we include pre-bridge electrification rate (proportion of household with electricity in 1991) as a control for logit and Oxaca-Blinder regressions for nightlights. For yield, pre-bridge standard deviation of rain which is an important determinant of adoption of irrigation is used as a control in the logit and Oxaca-blinder regressions in place of population.[14] The residuals from regressions using annual data may also display serial correlation. To remedy this, we follow suggestions of Bertrand, Duflo and Mulainathan (2009) and collapse data for nightlight and rice yield by taking three-year averages. All standard errors are clustered at the upazila level.

(5) Data Sources and Construction of the Samples

We utilize several data sources to estimate the effects of Jamuna bridge on resource reallocation and agricultural productivity (crop yield). The data on population and sectoral employment patterns are taken from three population censuses (1991, 2001 and 2011). We construct a subdistrict (upazila) level panel data set using the publicly available census unit records.[15] For the analysis of these outcome variables, we treat 1991 as the pre-bridge baseline, and 2001 as the short-run and 2011 as the long-run. The data on the luminosity of night lights are drawn from global satellite data. The night light data are available from 1992 to 2012 and also constitute a panel at the subdistrict level. We focus on the average nightlight luminosity per sq km. In contrast to population census and night light data, data on agricultural yields are available at the old district level though for a longer time period from 1988 to 2013.[16] Rainfall data are drawn from Bandyopadhyay and Skoufias (2012) and rice suitability index from Bangladesh Agricultural Research Council database. Crow-fly distances from upazila center to bridge location is computed using GIS software.

We use digital maps to identify the borders of upazilas over time and match all upazilas in 2000 and 2010 to 1990 upazilas. All censuses and surveys used The same master codes and names

[13] Rice suitability is a ranking of land in terms of its suitability for rice production where ranking is done on a scale of 1 to 5, 1 being best and 5 being least suitable. The ranking is done by agronomists considering soil type, ground water availability, rainfall, temperature etc.

[14] For a discussion on the importance of rainfall for adoption of irrigation in Bangladesh, see Emran and Shilpi (2018).

[15] Census data were downloaded from the IPMUSI website.

[16] There are 23 of old districts in the country.

for the upazilas are used in all surveys and censuses. Thus matching of upazilas that did not change boundaries has been straightforward. The matching for those upazlias that were split and/or recombined was done by superimposing digital maps from different years and using area weights to link the newly created upazilas to 1990's upazilas. Total number of upazilas in our data is 123 in the treatment hinterland, 122 in the control hinterland and 97 in the core (or center).[17] For yield data, we have 6 districts in control and 5 each in treatment and core.

(6) Preliminary Evidence

(6.1) Characteristics of Areas Connected by Jamuna Bridge

The Treatment Hinterland: The North-west region

In terms of observable characteristics, the treatment areas in the North-west region can be characterized as a hinterland. Columns 1 and 2 of Table 1 summarize the average characteristics of the subdistricts in the North-west and the core regions during the pre-bridge period. According to the estimates of head count ratio, the incidence of poverty in the North-west in 1995/96 was about 61.8 percent compared with 40 percent in the core that includes the capital city Dhaka. Average nightlight luminosity during 1992-1997 period in the North-west was about half of that in the center. The population census data for 1991 show that the North-west was significantly less urbanized (urban share of population 0.12 in NW vs 0.24 in center), more agricultural (0.81 vs 0.66), and much less densely populated (908 vs 2900/sqkm). The North-west region fared adversely in terms of industrial employment compared with core. The proportion of households with electricity in the North-west was about 0.08 compared with 0.19 in core. Overall, Table 1 confirms that the North-west region was a lagging region displaying characteristics of a hinterland during the pre-bridge period. One concern may be that while the North-west is lagging in terms of levels of different outcomes, regional convergence may imply higher trend growth in the North-west compared to the center. To check this possibility, we perform a t-test on the growth rates of nightlights which can not reject the null hypothesis of no difference at 10 percent significance level (p-value=0.15) (last column in Table 1).

[17] For nightlight data, we have the complete panel for additional 3 upazilas (1 each in all three regions). Dropping these 3 upazilas from our estimation sample does not affect any regression results.

The Comparison Hinterland: The Southern Region to be Connected by the Proposed Padma Bridge

To test the predictions regarding the effects of Jamuna bridge on the treatment hinterland outlined in propositions 1-3, we need data on a set of comparison subdistricts which are similar to the subdistricts in our treatment areas in the Jamuna hinterland region. The geography of Bangladesh along with the lack of bridges over large rivers help us identify such a comparison hinterland region. About 20 percent of the country's population in the Southern region are also cut-off from the economic center located at the capital city Dhaka by Padma river. A bridge similar in specification to Jamuna bridge had been proposed to connect this region to the capital city, Dhaka. The work on the construction of this bridge started only in December of 2015 under the current prime minister whose ancestral home is located in the southern region.

The long delay in the construction of the Padma bridge relative to the Jamuna bridge was due to couple of exogenous factors. Out of the two and a half decades that elapsed between the 1974 famine and the opening of the Jamuna bridge in 1998, leaders from the North-west region headed the government for 17 years.[18] Second, construction cost of such a major bridge is so large that government had to seek financing from donors. During the 1974 famine, the North-west region suffered disproportionate fatality as some of its districts were worse hit by the famine. Out of the 1.5 million people who perished in the famine, 100 thousand died in a single district located in the Jamuna hinterland (Rangpur) alone (Sen (1981)). As mentioned earlier, the incidence of poverty was the highest in North-west compared with all other regions. These factors made it easier to secure donor funding for the Jamuna bridge project.

(6.2) Pre-bridge Balance and Placebo Tests

Probability Weighting

As a first step to understanding whether the region (South) to be served by proposed Padma bridge provides a good counterfactual for the treatment region, we look at the summary statistics for the subdistricts in the treatment hinterland (North-west) and the comparison hinterland (South) areas during the pre-bridge period. In addition to comparing simple un-weighted means of variables, we also report the Logit Probability Weighted and Oaxaca-Blinder weighted means in Table 1,

[18] General Zia was in power from 1977 to 1981, General Ershad from 1983 to 1991, and Begum Zia from 1991 to 1996.

following Kline (2011) and Kline and Moretti (2014b).

The poverty rate in the control areas was somewhat smaller (55 percent) compared with that in our treatment (61 percent).[19] There is no statistically significant difference in the level or trend of rice yields between the treatment and comparison hinterlands. As evident from Table 1, the growth rates of nightlight luminosity in the treatment and control subdistricts are indistinguishable from each other during the pre-bridge period, allaying any concerns about trend differences between the two regions. The statistically significant differences are found only in the cases of employment levels and shares of services and agriculture: the treatment subdistricts in the North-west are more agricultural than the comparison areas in the south.

Doubly Robust Approach: Probability Weighting plus Regression Adjustment

The main take-away from the evidence in Table 1 is that while weighting reduces the difference in means in some cases, it alone is not sufficient to achieve balance, especially for the sectoral labor allocation variables. In this section, we provide evidence that a doubly robust approach that combines regression adjustments with probability weighting is effective in achieving balance in pre-bridge characteristics. It has been increasingly appreciated in the literature that a doubly-robust approach is more reliable than probability weighting alone.[20]

For variables from the population census, this exercise checks whether there are significant differences between the levels of our *outcome* variables between the treatment and control subdistricts. Note that balance in levels of observable characteristics is not necessary for our difference-in-difference design, but evidence of balance in levels of the variables can be reassuring. For nightlight and yield data, we also analyze the growth rates, as there are multiple periods of data are available from the pre-bridge period. These *false experiments* test whether, conditional on pre-bridge characteristics, our outcome variables are statistically different between the treatment and comparison areas, both in terms of their levels and trends (for nightlight and yield). Because the tests are done with data prior to the opening of the bridge, these falsification tests should be informative about any potential selection biases between the treatment and comparison subdistricts.

[19] Poverty rate estimates are at the broad regional level and thus we can not test whether they are statistically different between our treatment and comparison areas. Nevertheless, the difference between the two (61 vs. 55) is substantially smaller than their respective differences with poverty rate in the center (40 percent).

[20] We are thankful to Jeff Wooldridge for suggesting the combination of weighting and regression adjustment.

Table 2 reports the differences between the treatment and comparison hinterlands conditional on a vector of pre-bridge characteristics. The vector of pre-bridge characteristics includes population in 1991 (log), crow-fly distance to bridge location (log), index of rice suitability, rainfall (average and standard deviation) (log) in 1990. To test whether there is statistically significant differences, we include a dummy for the treatment region. Column 1 in Table 2 contains the estimates from the full sample using OLS, while columns 2 and 3 report the estimates from the trimmed sample using logit probability weights and Oaxaca-Blinder weights respectively. The upper 3 panels in Table 2 report the results for population density, employment structure, nightlights and rice yields respectively.

The evidence in Table 2 shows that, once we condition on a small set of pre-bridge characteristics, all the variables are balanced between the treatment and comparison areas. The magnitudes of the estimated coefficients are much smaller for weighted estimators and the difference between the coefficients estimated from two weighting schemes is also negligible. In Table 1, the treatment areas are found to have more agriculture and less services employment compared with the control areas. These differences, however, disappear once we use regression adjustments. It is reassuring that the statistical insignificance observed in Table 2 is due to substantial shrinking of the magnitudes of coefficient on the treatment dummy for the dependent variables for which significant differences are found in unconditional analysis, instead of blowing up of the standard errors.

As an additional diagnostic check, we take advantage of the longer time dimension of the data on rice yield and nightlights, and perform a placebo policy experiment where we restrict our sample to pre-bridge periods. We then take the mid-year of this restricted sample to be the year of a placebo bridge opening and perform the DID estimation. The results reported in the fourth panel of Table 2 show no statistically or numerically distinguishable effects of this fictitious bridge opening on yield (three-year average). We repeat the same exercise with annual data for nightlights and rice yields which are reported in the lower two panels. The results again show no statistically or numerically meaningful difference between the treatment and comparison hinterlands.[21] This is consistent with the notion that there were no significant trend differences between the treatment and control areas during the pre-bridge period.

[21] When we repeat this experiment with demeaned data, we find no statistically or numerically significant differences between treatment and control hinterlands during pre-bridge period.

(7) The Effects of Jamuna Bridge on Labor Allocation, Population Density and Productivity

We discuss the estimated effects of Jamuna bridge separately for the short- and long-runs, as the theoretical analysis above predicts substantial differences in the effects immediately after bridge opening and in the relatively longer run. The focus of our analysis is on the effects of Jamuna bridge on the treatment hinterland. We also provide a brief discussion on the effects on the core region, especially where it is relevant for interpretation of the evidence on the treatment hinterland.[22]

(7.1) The Short-run Effects

The estimates of the short-run effects of Jamuna bridge on the treatment hinterland (North-west) and the core region compared with the hinterland in the southern region are reported in the odd columns of Table 3. For the census data, 2001 is treated as the short-run, and. for the nightlight and yields data, the immediate post-bridge period (1998-2004) is defined as short-run.

The first important piece of evidence in Table 3 relates to the effects of bridge on population density in the short-run. Since the short-run is defined as a time period when labor mobility is not possible, we should not observe any significant effect on population density. The evidence from the fixed effect DID specification using OLS, LWRA and OBDR estimators are in columns (1), (3) and (5) respectively, and the robust conclusion from all three estimates is that there is no significant effect on population density, 3 years after the opening of the bridge. The evidence that there is no significant population movements across regions in response to the Jamuna bridge has important implications for the interpretation of the estimates, as discussed earlier in the empirical strategy section. This suggests that the estimated effects of Jamuna bridge in the short-run are not biased by "displacement" or relocation of population from the comparison regions, and the estimates can plausibly be interpreted as causal effects. A comparison of the results in the odd-numbered columns of Table 3 shows that the estimates are remarkably consistent across estimation methods and samples. For most of the cases, our preferred estimates from OBDR applied to the fixed effect DID model are slightly smaller in magnitude compared with the LWRA and the OLS estimates.

[22]We emphasize here that the estimates for the core cannot be given any causal interpretation, as the comparison is chosen to satisfy balance relative to the treatment hinterland. But the pattern of estimates for treatment hinterland and core relative to a common comparison area can be informative in understanding resource reallocation across three regions in response to the Jamuna bridge.

Our discussion below thus focuses mainly on the OBDR estimates.

The short-run estimates for the share of manufacturing employment in the treatment hinterland have negative sign but are not statistically different from zero. In contrast, the effect of bridge opening on the share of agricultural employment in the Jamuna hinterland (treatment) is negative and statistically significant. The decline in the share of agricultural employment seems puzzling as the North-west region has comparative advantage in agriculture. However, the estimated effect on the services employment provides a plausible explanation. The estimates in panel D of Table 3 show that the opening of bridge increased the share of labor allocated to the services sector by 12 percent in treatment areas compared with the comparison areas located in Padma hinterland. The evidence thus indicates that, in the short-run, the labor reallocation took place primarily from agriculture to services in the Jamuna hinterland. As outlined in proposition 1 above, the observed short run effects on the employment pattern in the treatment hinterland can be explained if certain production services such as trading and processing are needed only in the case of inter-regional trade. Specifically, the employment share of agriculture in the post-bridge period can decline if agricultural trade is more service intensive relative to manufacturing trade ($(1 - \beta - \phi_x) > \phi_x$), given that the treatment hinterland exports agricultural goods to the core region. This seems a plausible interpretation, considering the fact that agricultural products are bulky, and many are perishable, requiring quick transport and processing. The analysis thus underscores the need for going beyond the canonical 2×2 model to a 3-product economy that includes the services sector, especially trading services, to understand the pattern of resource reallocation and structural change following a large reduction in trade costs.

An interesting piece of evidence reported in panel E of Table 3 relates to the short-run effects of bridge on agricultural productivity as measured by rice yield; there is a negative and statistically significant effect in the treatment hinterland. This seems puzzling, because one would have expected a positive effect as prices of inputs such as fertilizer and pesticides go down in response to a more than 50 percent reduction in transport costs. One might argue that the lower prices of fertilizer and pesticide may not be sufficient for adoption of new technology by farmers, learning and agglomeration externalities might be important. As noted in the theoretical analysis, when technology adoption depends on learning and agglomeration externalities, we will observe positive co-movement in population density and productivity changes. But the evidence that agricultural productivity declined while population density did not change in the short-run suggests that the decline in productivity cannot be due to negative learning externalities and disagglomeration. A plausible explanation can be provided in terms of short-term labor constraint; as labor was reallocated from agriculture (panel C), the agricultural sector faced labor shortage in the short-run in the absence of migration from the other two regions. The labor shortage is likely to slow down the rate of technology adoption.[23] The last indicator of economic activity we report in Table 3 is the average nighlight luminosity in panel F: none of the estimates of the effects of bridge in the short run are statistically significant for the treatment hinterland. This is consistent with the finding that there is no change in the population density in the short-run.

In the short-run, the changes in the core region including the capital city Dhaka are broadly similar to those for the treatment hinterland in the North-west region: there is no significant effect on population density, or average nightlight luminosity, and a negative and statistically significant effect on the share of agricultural employment. However, the decline in the share of agricultural employment is relatively smaller in the core region.[24] There are also interesting differences: (i) the evidence suggests reallocation of labor from agriculture to both manufacturing and services although the effects are not estimated precisely, and (ii) there is no significant effect on agricultural productivity. This reallocation of labor away from agriculture in the core did not have any effect on yield perhaps because markets in the center were already integrated before the bridge, and consequently the bridge did not affect technology adoption pattern there in a significant manner.

(7.2) The Long-run Effects

For the long-run estimates, 2011 is treated as long run in census, 2005-2012 in nightlights and 2005-2013 in yield data. The long-run estimates are reported in the even columns of Table 3. The estimates show that the long-run effects are substantially different from the short-run effects. Focusing on the estimates from OBDR (column 6 of Table 3), the first important point to note is that the share of manufacturing employment in the treatment areas declines significantly relative to the comparison hinterland. Starting from a manufacturing share of 0.028, an estimated effect of (-0.009) implies about a third reduction in the manufacturing share in the treatment hinterland relative to the comparison hinterland. This is in contrast to the short-run evidence

[23] It is perhaps useful to emphasize here that the FE-DID estimates for the treatment hinterland do not imply that there was no productivity growth in agriculture, only that the productivity gain was lower than that in the comparison hinterland.

[24] The difference between the estimates for the treatment hinterland and core is statistically significant at the 5 percent level.

of no statistically significant effect on the manufacturing share of labor, and suggests significant deindustrialization in the treatment hinterland in the long-run. The conclusion that the Jamuna bridge precipitated deindustrialization in the newly connected hinterland in the North-west regions is supported by the evidence that the share of manufacturing employment increased significantly in the core region in the long run. The magnitude of the increase in the core is also quite substantial: the OBDR estimate in Table 3 implies an increase of about 78 percent (from 0.052 to 0.091) in the labor share of manufacturing in the core region. The contrasting evidence on the effects of bridge on the labor share of manufacturing in the treatment hinterland vs. the core region is exactly in line with the predictions of the core-periphery models in the tradition of Krugman (1991).[25]

The core-periphery models, are, however only partially consistent with the long-run evidence in Table 3. An important prediction of the core-periphery models is that population density declines with deindustrialization, as people leave the newly connected hinterland to the center as a result of agglomeration in the manufacturing sector. The evidence on population density in the treatment hinterland is opposite to the prediction of the core-periphery models: compared with the Padma hinterland, population density increases substantially (8 percent) in the treatment hinterland in the long-run, 13 years after the opening of the Jamuna bridge. Compared with the Padma hinterland, population density of the core region also increased substantially (11 percent higher). The estimates of the effects of Jamuna bridge on the population density thus imply that both the treatment hinterland and the core region gained at the expense of the comparison hinterland, a possibility shut-off by assumption in the standard 2-region core-periphery models. Note that the larger increase in population density in the core is consistent with more manufacturing employment there: at the baseline in 1991 (5.2 percent compared to 2.8 percent in treatment region).[26] It is also suggestive of stronger agglomeration economies in manufacturing relative to agriculture.

The pattern of labor allocation to agriculture and services in the long-run is also interesting and informative. The share of labor allocated to agriculture in the treatment hinterland seems to gain back some of the lost ground with time; after 13 years of the bridge opening, the effect of bridge on the share of agricultural labor retains a negative sign, but is numerically smaller and statistically weaker (not significant at the 5 percent level). This suggests that the short-run labor

[25] This is also consistent with the standard comparative advantage trade models because the treatment hinterland has comparative advantage in agriculture according to the land suitability index.

[26] Although the standard trade models do not focus on population density, one would expect higher population density in a region that has comparative advantage in manufacturing, as manufacturing is less land-intensive compared to agriculture.

shortage faced by agricultural sector is relaxed when migration from the comparison hinterland becomes feasible in the longer-run.[27]

The effects on the share of labor allocated to services in the treatment hinterland on the other hand become slightly stronger: the long-run estimate of the effects of bridge is significant at the 1 percent level, and the magnitude increases marginally from 0.023 (short-run) to 0.025 (long-run). About 40% of the increase in services share in the long run comes at the expense of the manufacturing, and the rest from agriculture. In the core region, there is a significant decline (-0.060) in agriculture's share in the long-run which is offset by an increase in industry's share by 0.04 and services by 0.02. The results thus suggest contrasting structural transformation in employment pattern in the long run, with the employment structure in the center becoming more manufacturing oriented, and that in the treatment hinterland more service oriented.

In contrast to the short-run adverse effects on agricultural productivity, the long-run estimate from OBDR (see column 6, panel E of Table 3) shows a positive and statistically significant impact in the treatment hinterland. In the longer run (2005-2013), rice yield grew by 5.2 percent more in the treatment hinterland compared with the Padma hinterland. The gains in agricultural productivity probably reflects a combination of agglomeration externalities (learning) due to higher population density and a relaxation of the labor constraint faced in the short-run because of in-migration from the other regions. As noted earlier, if learning externalities (agglomeration) constitute a primary mechanism behind productivity growth in agriculture, then we expect close positive co-movement between population density and agricultural productivity. Since the increase in population density is larger (11 percent) in the core region when compared to that in the treatment hinterland (8 percent), we should thus observe a higher productivity growth in agriculture in the core region if the primary mechanism is, in fact, learning and agglomeration externalities. The evidence in Table 3 vindicates this prediction: the core region experienced a 6.1 percent higher productivity as a result of the bridge as compared to the 5.2 percent higher productivity in the treatment hinterland.

Along with population density, we also examine the long-run impact of bridge on economic density using the average nightlight luminosity as a second indicator.[28] The estimates reported

[27] This also suggests that in the longer run, say after 30 years of bridge opening, the share of labor in agriculture in the treatment hinterland may gain more ground. It is highly unlikely that the spatial adjustments, especially migration, has worked out fully in 13 years after the opening of the bridge.

[28] Economic density is usually captured by nominal GDP. In the absence of subnational data on GDP, we use average luminosity of nightlight which is found to be significantly and positively correlated with GDP in most

in the last panel of Table 3 imply a 2.8 percentage point additional growth of average luminosity in the treatment and a 4.3 percentage point in the core region. The evidence that the increase in the average nighlight luminosity is higher in the core region is consistent with the earlier evidence on population density and productivity effects of bridge.

The long run estimates confirm a major concern in the literature that transport infrastructure may lead to significant reallocation of population making it difficult to interpret the size of treatment effects. However, the labor allocation measures we use are expressed as shares of total labor in a region. Thus the estimated effects on labor shares may not suffer significantly from the "displacement bias" a major concern for other variables such as population density and average night light luminosity which have been the focus of the recent literature. A related concern is whether increased trade between core and treatment hinterland has a pecuniary externality in terms of shrinking trading zone in control hinterland. This would lead to a decrease in the employment share of services because most of these services are required for only inter-regional trade. The evidence on the services share in comparison hinterland, however, alleys any concerns for pecuniary spill-over effects: the share of services increased from 0.248 in 1991 to 0.311 in 2011. All of the dependent variables for treatment and control hinterlands moved in the same direction over the entire sample period.

(7.3) Robustness Checks and Alternative Interpretations

Robustness Checks

We perform additional robustness checks. The regression controls include crow-fly distance which is a time-invariant variable. One may be concerned that crow-fly distance might be capturing part of the trade cost. To address this, we drop crow-fly distance from the set of controls. The results reported in an online appendix show little or no change in the estimates of bridge effects. A second concern is that large bridge construction is accompanied by other interventions at the same time particularly in terms of expansion of electricity. Indeed, Jamuna bridge construction also led to the second east-west electrical inter-connector which became operational in 2009 (ADB, project brief). In a second robustness check, we included proportion of household with electricity in 2011 as an additional control. The results reported in the online appendix indicate no difference in the estimates of bridge effects.

countries (Henderson et al. (2012)).

Alternative Interpretation

The theoretical model and the empirical analysis both focus on the supply side mechanisms to explain the observed changes in the sectoral labor shares in response to Jamuna bridge. One may wonder whether a demand side explanation based on non-homothetic preference where services are more income elastic than agriculture may also explain the pattern of structural change as measured by labor share. Both the short-run and long-run estimates of the effects on the labor share of services sector in the treatment hinterland and the core region reject the possibility that nonhomothetic demand with high income elasticity of services is the primary driving force at work in our data.

Since the opening of bridge increases indirect utility/real wage in both the center and treatment hinterlands, its effects on services share should be positive assuming a higher income elasticity. The short-run evidence in Table 3 shows a positive effect in the case of the treatment hinterland, but a statistically insignificant effect in the core region which contradicts the nonhomothetic demand explanation for the core region. Note that the shortrun gain in real income is likely to be higher in the core region when the share of household consumption expenditure devoted to food is high, as is the case in Bangladesh, and because the core imports food from the hinterland.[29] The nonhomotheic demand would thus imply a larger positive effect on the share of services in the core region in the short-run which does not appear to be the case.

In the long-run, labor mobility across the regions tends to equalize the real income/utility, implying that the increase in the labor share of the services sector due to the Engel curve effect should be broadly similar across regions including control hinterland. This would imply a smaller estimate for services share in the long-run relative to that in the short-run.The evidence in Table 3 and online appendix shows clearly that long-run estimates are slightly larger than respective short-run estimates. The evidence thus does not support demand side as the main mechanism at work.

(8) Spatial Heterogeneity

An important prediction of the theoretical model is that the effects of the lower trade costs after the opening of the bridge on the intersectoral employment pattern should be much starker in

[29] The theoretical analysis ignores possible differences in share of expenditure devoted to agricultural goods vs. manufacturing for the sake of simplicity.

areas that move from autarky during pre-bridge period to trade integration in the post bridge period. These areas moves from more diversified to more specialized employment pattern. This heterogeneity may not be present in the case of population density and productivity which tend to shift upward more uniformly with declining trade costs.

To test these implications of the model empirically, one needs to know the location of the extensive margin. It is not possible to determine the extensive margin of trade before or after the bridge on a priori basis. Given the distance between the center and the hinterlands, the areas closer to the bridge are more likely to be in the integrated subregions during the pre-bridge period. This allows us to incrementally take away the areas close to the riverbank from the sample and explore how the estimates vary across the truncated samples, where truncation is defined using different distance cut-offs. We start by dropping all the subdistricts within 50 kilometers (km) of the bridge location (Jamuna for treatment, Padma for the comparison hinterland, and the closest of two for the center) and increase the distance cut-off to 75km and 100 km. Assuming a travel speed of 35 km per hour and 3-4 hours for river-crossing during the pre-bridge period, the border of integrated subregion in the treatment hinterland can be expected to be somewhere between 125 km and 175 km. The opening of the bridge had perhaps extended that border to 250km and beyond. In this case, we expect to find larger impacts on employment pattern in the successive truncated samples.[30] On the other hand, if the newly integrated region is located at a closer distance, then we expect to find the effects to be larger at the beginning and a tapering off as we move on to the more distant subdistricts.

Table 4 reports results from OBDR regressions estimated for alternative truncated samples based on different distance cut-offs. For the treatment hinterland, the estimated effects of bridge on population density, nightlight luminosity and yields do not vary significantly across different samples, confirming the a priori expectations of uniform effects on these variables regardless of distance. For manufacturing employment, the decrease in the employment share in the longer run is larger in the truncated samples (between -0.014 and -0.015) compared with the full sample estimate (-0.010). For services, the short-run effects are slightly higher in the truncated samples compared with the full sample, particularly when the subdistricts up to 75 km are dropped from the sample. In the longer run, the effects on the share of labor in the services sector are much larger, and increases with the distance cutoffs. For instance, the estimated increase in the services

[30] Using higher distance cutoff (e.g. 125km) reduces sample size drastically (only 91 subdistricts).

share in the sample of subdistricts 100 km away from the bridge is 0.044 compared with 0.025 for the full sample. The results for the decrease in agriculture's share are similar to that for the share of services sector.

The estimates suggest interesting differences in the pattern of structural transformation across different truncated samples. The increase in the share of services in the sample of subdistricts more than 75 km away from the bridge in the longer run comes from a decline in the manufacturing (40%) and the agriculture (60%), whereas in the sample more than 100km away, it comes mostly from a decline in the agriculture (70%). Overall, the results for treatment hinterlands lend strong support to the heterogeneity in the impacts of bridge on employment pattern predicted by the theoretical model.

The estimates for the core region reported in Table 4 suggest that the increase in population density has been concentrated in areas within 75 km of the bridge, and that in the short-run, population from the subdistricts farther than 75 km may have moved to the subregion closer to the bridge. Similar to population density, the increase in the employment share of manufacturing is also concentrated in the areas near the bridge. The estimates also display non-linear pattern with increase (decrease) in services (agriculture's) share and nightlight luminosity largest in subdistricts 75km away from bridge. Only in the case of rice yield, we find larger increase in subdistricts father than 100km away. Overall, the results for employment and population density suggest a smaller expansion of the integrated subregion in core compared to treatment hinterland in response to the bridge.

Conclusions

We provide an analysis of the effects of reduction in trade costs on structural change and agricultural productivity in a developing country, using the Jamuna bridge in Bangladesh as a case study. Although there has been a recent revival of interest in understanding the effects of transport infrastructure on spatial resource allocation, and productivity, most of the analysis focuses on the road and railway infrastructure.[31] The construction of Jamuna bridge reduced transport costs from the poor North-west hinterland to the capital city by more than 50 percent. This large reduction in trade costs offers us an excellent opportunity to understand the role played by trade

[31] In his excellent review of the recent literature on gains from market integration, Donaldson (2015) does not cite any research that focuses on the effects of bridge construction.

frictions in a developing economy.

A three-region and three-product spatial general equilibrium model is developed to generate testable predictions different from the standard core-periphery and trade models. For the empirical analysis, we take advantage of a upazila level panel data set and implement a difference-in-difference design based on idiosyncratic political factors. The evidence from doubly-robust estimators, using the Padma hinterland as the comparison which remains cut-off from the core region including the capital city, we find that Jamuna Bridge led to significant deindustrialization in the treatment hinterland in the long-run, but increased manufacturing employment in the core. This provides support for one of the central predictions of the core-periphery models, but the evidence also contradicts the core-periphery model as there are significant positive effects on population density, agricultural productivity and night-lights. Taken together, the evidence suggests that despite deindustrialization, Jamuna bridge did not hollow out the Jamuna hinterland through backwash effects, instead led to economic revival. The effects of trade cost reduction on intersectoral labor allocation are spatially heterogeneous; the estimates show smaller effects in the areas adjacent to the bridge, which is consistent with the theoretical analysis if these areas were not in autarky in the absence of the bridge. The adverse effects on manufacturing employment (deindustrialization) are most pronounced in the intermediate distance from the bridge.

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Figure 1: Geography of the country with two rivers and three regions

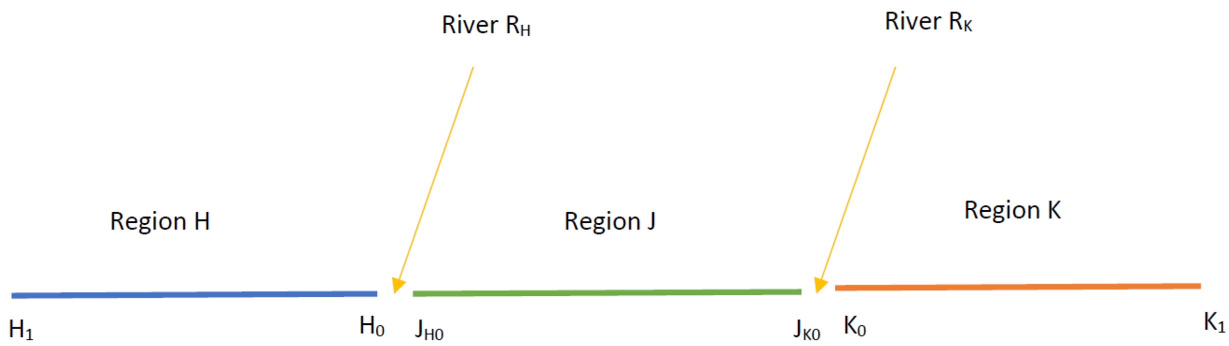

Figure 2: Short and Long run impacts of bridge on Population Distribution in Region H

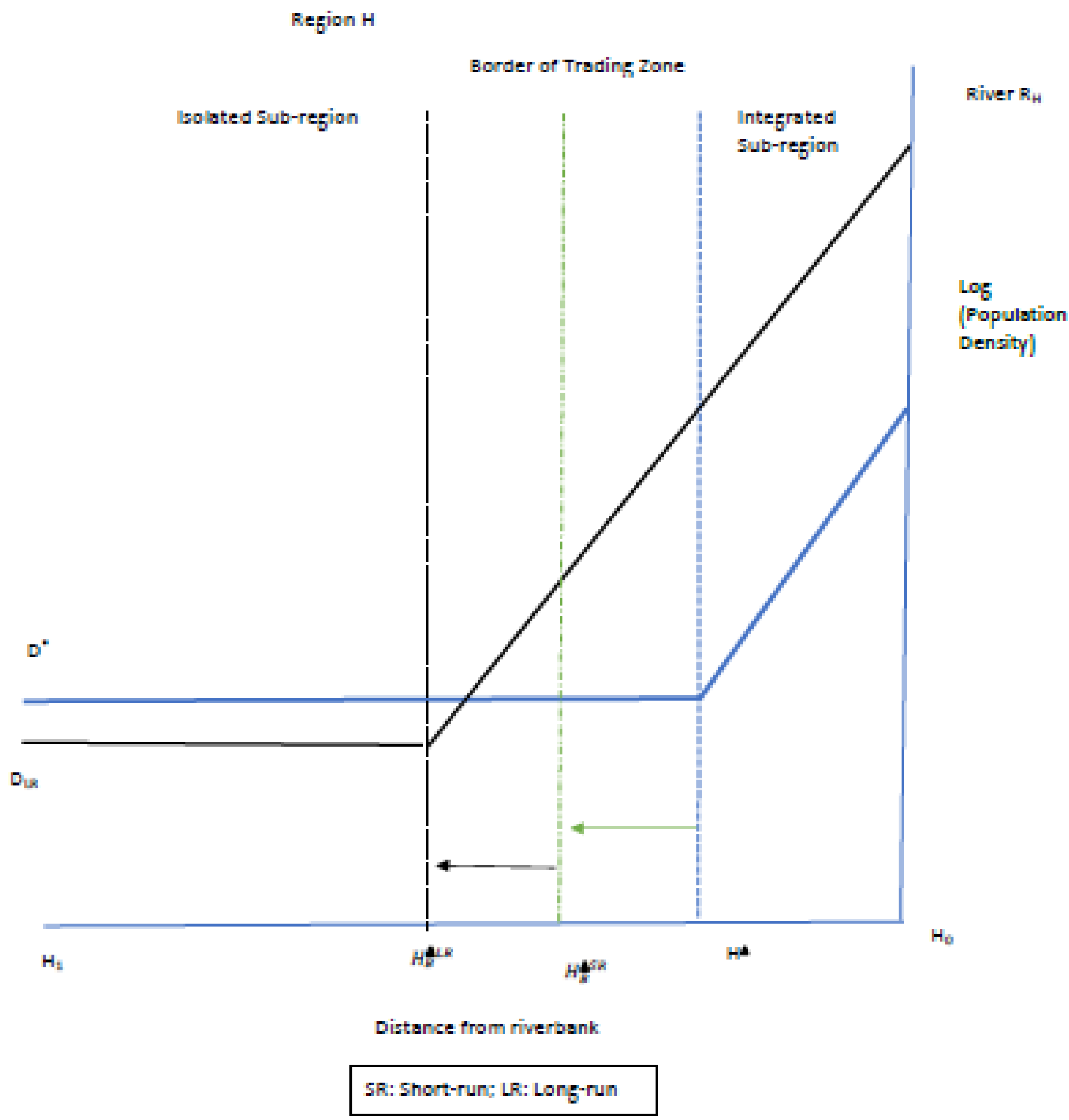

Table 1: Pre-Bridge Sample Means in Hinterlands and Core/Center

	Core/Center (Capital City & adjacent area)	North-West (Jamuna Bridge)	South (Padma Bridge)			P-value of difference between			
			Full	Trimmed Sample		North-West and South			North-West & Center
			Sample	Logit Weight	OB weight	No Weight	Logit Weight	OB weight	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(1 vs.2)
Poverty headcount ratio in 1995/96	40.1	61.8	55.0						
1991 Population Characteristics									
Population (log)	12.37	12.15	12.11	12.17	12.16	0.49	0.75	0.92	0.00
Population Density per sqkm	2,900	908	1,053	1,017	1,031	0.56	0.65	0.62	0.10
% of household with electricity	0.14	0.08	0.08	0.09	0.09	0.80	0.60	0.58	0.01
Share of urban in total population	0.20	0.12	0.14	0.14	0.14	0.33	0.32	0.28	0.02
Employment (log)									
Total	10.90	10.75	10.59	10.66	10.64	0.01	0.11	0.07	0.02
Industry	7.13	6.53	6.56	6.62	6.61	0.80	0.53	0.58	0.00
Services	9.33	8.80	9.11	9.20	9.19	0.00	0.00	0.00	0.00
Agriculture	10.38	10.52	10.23	10.28	10.26	0.00	0.00	0.00	0.12
Share of total employment in									
Industry	0.052	0.028	0.028	0.027	0.027	0.972	0.872	0.946	0.005
Services	0.252	0.161	0.248	0.254	0.255	0.000	0.000	0.000	0.000
Agriculture	0.697	0.812	0.724	0.719	0.718	0.000	0.000	0.000	0.000
Average luminosity (log)									
1992-1997 Nightlight Levels	1.77	1.31	1.24	1.15	1.16	0.39	0.07	0.11	0.00
1992-1997 Nightlight Changes	0.02	0.01	0.01	0.01	0.01	0.14	0.14	0.15	0.15
1988-1997 Rice yield (mt/ha)									
Log (rice yield)	0.99	1.02	0.98	0.94	0.94	0.51	0.17	0.07	0.20
Av. Change in log (Rice yield)	-0.16	-0.15	-0.14	-0.14	-0.14	0.60	0.58	0.45	0.02

Note: The unit of observation is sub-district (upazila) for everything except rice yield. Unit of observation for rice yield is former district. The trimmed sample is obtained by dropping control (South) upazilas/ districts which, based on pre-bridge characteristics have a predicted probability of treatment in the lowest 5 percent. Data on employment are from population censuses, nightlight from satellite data and yield from Statistical Yearbooks. Annual yield and nightlight data are averaged over three years and change is defined as difference between consecutive three-year averages. Logit weights are inverse probability weights based on logit regression of treatment status on pre-bridge characteristics. Oaxaca-Blinder (OB) weights are estimated using a procedure suggested by Kline (2011). Both logit and OB regressions used the same set of pre-bridge controls.

Table 2: Core vs. Treatment and Control Hinterlands during Pre-bridge period: Placebo Regressions

	Full Sample	Trimmed Sample	
	OLS	LWRA	OBDR
Population density (log)	0.185	0.158	0.152
	(0.112)	(0.125)	(0.125)
Share of total employment in			
Industry	0.006	0.002	0.002
	(0.006)	(0.006)	(0.006)
Services	-0.020	-0.019	-0.020
	(0.020)	(0.021)	(0.021)
Agriculture	0.014	0.017	0.018
	(0.022)	(0.023)	(0.023)
No. of Observations/Upazilas	243	236	236
1992-1997 Nightlight Changes			
Average luminosity (log) (3-year av.)	0.036	0.009	0.009
	(0.023)	(0.025)	(0.026)
No. of observations/Upazilas	247	240	240
1988-1997 Rice yield (mt/ha)			
Change in log (Rice yield) (3-year av.)	0.013	0.010	0.012
	(0.030)	(0.027)	(0.027)
No. of Districts (observations)	11 (33)	10(30)	10(30)
Placebo Policy Change			
1988-1997 Rice yield (mt/ha)			
Change in log (Rice yield) (3-year av.)	-0.001	-0.035	-0.024
	(0.068)	(0.094)	(0.078)
No. of Districts (observations)	11 (33)	10(30)	10(30)
Annual Change in log (Rice yield)	0.025	-0.026	-0.013
	(0.068)	(0.091)	(0.074)
No. of Districts (observations)	11(110)	10(100)	10(100)
1992-1997 Nightlight Changes			
Annual Average luminosity (log)	-0.008	-0.018	-0.021
	(0.013)	(0.013)	(0.013)
No. of Upazilas (observations)	247(1,215)	241(1,190)	241(1,190)

Note: The results for each outcome are reported in two adjacent rows. LWRA: Logit Weighted and Regression Adjusted; OBDR: Doubly Robust Oaxaca-Blinder Reweighted. The upper cell provides the difference-in-difference estimate of coefficient of treatment dummy and lower cell its robust standard errors on parenthesis. Column 1 provides the simple OLS results for the full sample, columns 2 and 3 inverse probability weighted and Oxaca-Blinder weighted estimates for trimmed sample respectively. For employment and nightlight, controls in each regression includes log (population in 1991), log (crow-fly distance to bridge location), log (average rainfall in 1990), log (standard deviation of rainfall in 1990) and ranking of land for its suitability for rice production. To be consistent with logit and Oaxaca-Blinder regressions, yield regressions include the same set of controls except log (population in 1991). Standard errors are clustered at upazila level. Legend: *** p<0.01, ** p<0.05, * p<0.1

Table 3: Jamuna Bridge and population density, employment structure and agricultural productivity in Core vs. Hinterland: DID-FE Results

	Full Sample		Trimmed Sample			
	DID-FE		DID-FE-LWRA		DID-FE-OBDR	
	SR	LR	SR	LR	SR	LR
Log (Population Density)	Panel A					
North-West	0.017	0.093***	0.010	0.080***	0.009	0.080***
	(0.012)	(0.016)	(0.125)	(0.017)	(0.014)	(0.017)
Core/Center	0.024	0.127***	0.017	0.114***	0.016	0.113***
	(0.023)	(0.034)	(0.028)	(0.035)	(0.024)	(0.035)
Employment in Industry (prop. of total)	Panel B					
North-West	-0.001	-0.013***	-0.001	-0.009*	-0.001	-0.009*
	(0.003)	(0.005)	(0.003)	(0.005)	(0.003)	(0.005)
Core/Center	0.007	0.035***	0.006	0.039***	0.006	0.039***
	(0.005)	(0.010)	(0.004)	(0.010)	(0.004)	(0.010)
Employment in Agriculture (prop. of total)	Panel C					
North-West	-0.018***	-0.007	-0.022***	-0.015	-0.022***	-0.015*
	(0.006)	(0.009)	(0.006)	(0.009)	(0.006)	(0.009)
Core/Center	-0.015**	-0.051***	-0.019**	-0.058***	-0.019**	-0.059***
	(0.008)	(0.012)	(0.008)	(0.012)	(0.008)	(0.012)
Employment in Services (prop. of total)	Panel D					
North-West	0.019***	0.020**	0.023***	0.024***	0.023***	0.025***
	(0.005)	(0.008)	(0.005)	(0.008)	(0.006)	(0.008)
Core/Center	0.009	0.015	0.013	0.019*	0.013	0.020*
	(0.008)	(0.010)	(0.008)	(0.010)	(0.008)	(0.010)
Observations	1,026	1,026	1,005	1,005	1,005	1,005
Difference in log (Yield per hectare)	Panel E					
North-West	-0.046**	0.050*	-0.049**	0.053*	-0.043*	0.052**
	(0.021)	(0.026)	(0.020)	(0.028)	(0.021)	(0.023)
Core/Center	0.002	0.058*	0.000	0.061*	0.006	0.061**
	(0.024)	(0.028)	(0.022)	(0.030)	(0.024)	(0.025)
Observations	128	128	120	120	120	120
Difference in log (Nightlight luminosity)	Panel F					
North-West	0.006	0.019	0.019	0.027**	0.020	0.028**
	(0.014)	(0.012)	(0.014)	(0.012)	(0.014)	(0.012)
Core/Center	0.027	0.034**	0.039**	0.042***	0.041**	0.043***
	(0.020)	(0.016)	(0.020)	(0.015)	(0.020)	(0.015)
Observations	2,070	2,070	2,028	2,028	2,028	2,028

Note: SR stands for short-run (1998-2004) and LR for long run (after 2004). LWRA: Logit Weighted and Regression Adjusted; OBDR: Doubly Robust Oaxaca-Blinder Reweighted. Each panel reports results for a dependent variable. Columns 1 & 2 provide the simple OLS results for the full sample, columns 3-4 and 5-6 inverse probability weighted and Oxaca-Blinder weighted estimates for trimmed sample respectively. Odd numbered columns report short-run and even numbered columns long-run estimates and standard errors. The estimate and standard errors for north-west (treatment) are in upper two rows and for core (center) in the lower two rows. For employment and nightlight, controls in each regression includes log (population in 1991), log (crow-fly distance to bridge location), log (average rainfall in 1990), log (standard deviation of rainfall in 1990) and ranking of land for its suitability for rice production. To be consistent with logit and Oaxaca-Blinder regressions, yield regressions include the same set of controls except log (population in 1991). Standard errors are clustered at upazila level. Legend: *** p<0.01, ** p<0.05, * p<0.1

Table 4: Heterogeneity of impacts with respect to distance from bridge location: DID-FE results

	Trimmed Sample: OBDR					
	50km		75km		100km	
	SR	LR	SR	LR	SR	LR
Log (Population Density)			Panel A			
North-West	0.005	0.074***	0.006	0.072***	0.002	0.074***
	(0.015)	(0.018)	(0.125)	(0.020)	(0.022)	(0.026)
Core/Center	0.004	0.106***	-0.028*	0.026	-0.037	0.019
	(0.022)	(0.036)	(0.028)	(0.021)	(0.022)	(0.029)
Employment in Industry (prop. of total)			Panel B			
North-West	-0.000	-0.014***	0.000	-0.015***	-0.003	-0.013**
	(0.003)	(0.005)	(0.003)	(0.005)	(0.003)	(0.006)
Core/Center	0.009**	0.040***	0.002	0.000	-0.000	0.001
	(0.004)	(0.013)	(0.003)	(0.006)	(0.002)	(0.008)
Employment in Agriculture (prop. of total)			Panel C			
North-West	-0.024***	-0.016*	-0.028***	-0.022**	-0.021***	-0.031**
	(0.006)	(0.010)	(0.007)	(0.010)	(0.007)	(0.013)
Core/Center	-0.032***	-0.071***	-0.029***	-0.033**	-0.021***	-0.025
	(0.007)	(0.015)	(0.007)	(0.014)	(0.008)	(0.017)
Employment in Services (prop. of total)			Panel D			
North-West	0.024***	0.030***	0.028***	0.037***	0.024***	0.044***
	(0.006)	(0.009)	(0.006)	(0.009)	(0.007)	(0.012)
Core/Center	0.024***	0.031***	0.027***	0.033***	0.021***	0.024*
	(0.007)	(0.010)	(0.007)	(0.011)	(0.008)	(0.013)
Observations	837	837	666	666	453	453
Difference in log (Yield per hectare)			Panel E			
North-West	-0.046*	0.046*	-0.046	0.046	-0.038	0.061
	(0.025)	(0.026)	(0.026)	(0.026)	(0.037)	(0.038)
Core/Center	0.018	0.058*	0.024	0.049	0.011	0.094**
	(0.024)	(0.030)	(0.027)	(0.040)	(0.027)	(0.038)
Observations	96	96	80	80	56	56
Difference in log (Nightlight luminosity)			Panel F			
North-West	0.022	0.035***	0.024	0.035**	0.022	0.044***
	(0.014)	(0.013)	(0.015)	(0.014)	(0.018)	(0.015)
Core/Center	0.091***	0.079***	0.143***	0.110***	0.108***	0.074***
	(0.020)	(0.016)	(0.019)	(0.016)	(0.021)	(0.017)
Observations	1,692	1,692	1,350	1,350	912	912

Note: SR stands for short-run (1998-2004) and LR for long run (after 2004). LWRA: Logit Weighted and Regression Adjusted; OBDR: Doubly Robust Oaxaca-Blinder Reweighted. Each panel reports results for a dependent variable. The estimates are Oxaca-Blinder weighted estimates from trimmed sample. The distance cut-off in the second row indicates sample for which regressions are estimated. Distance cut-off "50km" indicates the sample that dropped upazilas that are within 50 km of bridge location. Odd numbered columns report short-run and even numbered columns long-run estimates and standard errors. The estimate and standard errors for north-west (treatment) are in upper two rows and for core (center) in the lower two rows. For employment and nightlight, controls in each regression includes log (population in 1991), log (crow-fly distance to bridge location), log (average rainfall in 1990), log (standard deviation of rainfall in 1990) and ranking of land for its suitability for rice production. To be consistent with logit and Oaxaca-Blinder regressions, yield regressions include the same set of controls except log (population in 1991). Standard errors are clustered at upazila level. Legend: *** p<0.01, ** p<0.05, * p<0.1

Table A.1: Robustness checks

	No distance control		Include electricity	
	SR	LR	SR	LR
Log (Population Density)	Panel A			
North-West	0.009	0.080***	0.009	0.080***
	(0.014)	(0.017)	(0.125)	(0.017)
Core/Center	0.016	0.113***	0.016	0.113***
	(0.024)	(0.035)	(0.028)	(0.035)
Employment in Industry (prop. of total)	Panel B			
North-West	-0.001	-0.009*	-0.001	-0.009*
	(0.003)	(0.005)	(0.003)	(0.005)
Core/Center	0.006	0.039***	0.006	0.039***
	(0.004)	(0.010)	(0.004)	(0.010)
Employment in Agriculture (prop. of total)	Panel C			
North-West	-0.022***	-0.015*	-0.022***	-0.015*
	(0.006)	(0.009)	(0.006)	(0.009)
Core/Center	-0.019**	-0.059***	-0.019**	-0.059***
	(0.008)	(0.012)	(0.008)	(0.012)
Employment in Services (prop. of total)	Panel D			
North-West	0.023***	0.025***	0.023***	0.025***
	(0.006)	(0.008)	(0.006)	(0.008)
Core/Center	0.013	0.020*	0.013	0.020*
	(0.008)	(0.010)	(0.008)	(0.010)
Observations	1,005	1,005	1,005	1,005
Difference in log (Yield per hectare)	Panel E			
North-West	-0.043*	0.052**	-0.043*	0.052**
	(0.021)	(0.023)	(0.021)	(0.023)
Core/Center	0.006	0.061**	0.006	0.061**
	(0.024)	(0.025)	(0.024)	(0.025)
Observations	120	120	120	120
Difference in log (Nightlight luminosity)	Panel F			
North-West	0.020	0.028**	0.020	0.028**
	(0.014)	(0.012)	(0.014)	(0.012)
Core/Center	0.041**	0.043***	0.041**	0.043***
	(0.020)	(0.015)	(0.020)	(0.015)
Observations	2,028	2,028	2,028	2,028

Note: SR stands for short-run (1998-2004) and LR for long run (after 2004). Each panel reports results for a dependent variable. The estimates are Oxaca-Blinder weighted estimates from trimmed sample. The distance cut-off in the second row indicates sample for which regressions are estimated. Distance cut-off "50km" indicates the sample that dropped upazilas that are within 50 km of bridge location. Odd numbered columns report short-run and even numbered columns long-run estimates and standard errors. The estimate and standard errors for north-west (treatment) are in upper two rows and for core (center) in the lower two rows. For employment and nightlight, controls in each regression includes log (population in 1991), log (crow-fly distance to bridge location), log (average rainfall in 1990), log (standard deviation of rainfall in 1990) and ranking of land for its suitability for rice production. To be consistent with logit and Oaxaca-Blinder regressions, yield regressions include the same set of controls except log (population in 1991). Standard errors are clustered at upazila level. Legend: *** p<0.01, ** p<0.05, * p<0.1

ONLINE APPENDIX : NOT FOR PUBLICATION

In this appendix we present the theoretical model used in the analysis with full details. To avoid any discontinuity in reading, we discuss the model including the parts included in the main text of the paper.

(A.1) A MODEL of THREE-REGION and THREE-PRODUCT ECONOMY

We develop a model with the following features: (1) there are three regions separated by two rivers, and the industrial core is located in between two rivers, (2) three goods: agriculture, manufacturing, and services, (3) technological change in agriculture and manufacturing.

THE BASIC SET-UP

Geography

We consider the geography where all possible locations are ordered along a line between the interval $[H_1, K_1]$ (Figure 1). The line is divided into three segments by the presence of two rivers. The first river (R_H) is located closer to H_1 and the riverbanks are denoted as $H_0$and J_{0H}. The second river (R_K) is located closer to K_1 and its banks are denoted as J_{0K} and K_0. As shown in Figure 1, the presence of rivers defines three regions: $H = [H_1, H_0]$; $J = [J_{0H}, J_{0K}]$; and $K = [K_0, K_1]$. There are continuum of locations in each of the regions. Each location in region H is indexed by h, where h depicts the distance from riverbank H_0. Similarly each location in region J is indexed by j which shows the distance from river bank J_{0H} and in region K by k which shows the distance from riverbank K_0. In the absence of bridges, each river is crossed by using ferry. Two rivers are identical in width and water flow leading to identical cost of ferry. The cost of ferry is ($F_H = F_K = F$). Shipping of a good between two locations across any of the rivers involves an iceberg cost $e^{\tau d+F}$ where τ is a positive constant and d is the distance between the locations. Each location i is endowed with $T_i = T > 0, : i \in \{H, J, K\}$ units of land which is location specific. There is a mass of N workers in this economy each supplying 1 unit of labor inelastically. Labor is mobile across all locations within each region in the short run but mobile across regions in long run. Regions H and K are identical to each other with one exception that they are located on either sides of region J.

Production

Each region can produce two goods: manufacturing (m), agriculture (x), and two different types of services (s), one consumed by individuals and the other used in production. Production services include processing, trading and logistic services.[1] While regions can trade in agriculture and manufacturing goods, services are assumed to be non-traded. Manufacturing and agriculture are produced by combining labor, land and production services whereas production of both types of services requires only labor. Total factor productivity for each product in a given region may depend on regional characteristics such as climate, the extent of technology adoption in agriculture, and employment density for manufacturing.

The simple CRS production technologies for agriculture and manufacturing and three types of services are described as:

$$\begin{aligned} Q_{xi} &= A_{xi}T_{xi}^{\beta}S_{xi}^{1-\beta-\phi_x}L_{xi}^{\phi_x}; \qquad Q_{mi} = A_{mi}T_{mi}^{\beta}S_{mi}^{1-\beta-\phi_m}L_{mi}^{\phi_m}; \\ Q_{s_{ci}} &= A_{si}L_{si}; \qquad Q_{s_{xi}} = A_{xsi}L_{xsi}; \qquad Q_{s_{mi}} = A_{msi}L_{msi}; \quad i \in [H_1, K_1] \end{aligned}$$

Where s_{ci} is consumer services and s_{xi} and s_{mi} are production services for agriculture and manufacturing respectively. Total factor productivities in agriculture and manufacturing in a location i can be described as:

$$A_{xi} = \bar{A}_{xi}n_i^{\alpha_x};\ A_{mi} = \bar{A}_{mi}n_i^{\alpha_m}; \quad \bar{A}_{xh} = \bar{A}_{xk} > \bar{A}_{xj}; \quad \bar{A}_{mh} = \bar{A}_{mk} < \bar{A}_{mj}$$

where $\bar{A}_{xi}$ and $\bar{A}_{mi}$ are region specific productivity parameters (first nature geography) and $n_i = \frac{N_i}{T_i}$ is population density and $0 < \alpha_x, \alpha_m < 1-\beta$. Total factor productivities in both agriculture and manufacturing in a location are assumed to depend on its population density. This specification of factor productivity is a standard way of capturing agglomeration externalities in the manufacturing sector. Agglomeration economy in manufacturing arises from closer input-output relationship, thick labor market and learning externalities. A prominent theme in the agricultural economics literature is that technology adoption in agriculture is subject to important network and learning externalities. The network externality may arise, for example, from the need to build a marketing infrastructure for trading of inputs and outputs (Besley and Case (1993); Emran and Shilpi (2002)). Moreover, farmers may care about other's adoption decisions if early adopters teach late adopters about the viability of the technology when returns to adoption are uncertain (Besley and Case, 1993). Consequently, adoption of new technology in agriculture is often modeled to depend on existing stock of knowledge and network, and population density is a good proxy for both of these factors. Unlike manufacturing and agriculture, factor productivity in services is not affected by population density, and is assumed to be the same across regions. We assume that region J has comparative advantage in the production of manufacturing (m) and region H (and K) has in the production of agriculture (x).

[1] While these services are important for manufacturing, they are particularly relevant for agricultural trade. Most agricultural production is done by small family farms and exporting it to other regions involves an apparatus of traders and processors for collection, sorting, processing and shipping.

Each sector is characterized by perfect competition at each location. Constant returns to scale, free entry and profit maximization by the firms imply that in equilibrium, the following marginal conditions hold (let q index manufacturing and agricultural goods, i.e., $q \in [x, m]$:

$$\phi_q A_{qi} T_{qi}^{\beta} S_{qi}^{1-\beta-\phi_q} L_{qi}^{\phi_q - 1} = \frac{W_i}{P_{qi}} = \frac{\phi_q Q_{qi}}{L_{qi}};\ q \in (m, x) \tag{1}$$

$$(1-\beta-\phi_q) A_{qi} T_{qi}^{\beta} S_{qi}^{-\beta-\phi_q} L_{qi}^{\phi_q} = \frac{P_{qsi}}{P_{qi}} = \frac{(1-\beta-\phi_q) Q_{qi}}{S_{qi}};\ q \in (m, x) \tag{2}$$

$$\beta A_{qi} T_{qi}^{\beta-1} S_{qi}^{1-\beta-\phi_q} L_{qi}^{\phi_q} = \frac{r_i}{P_{qi}};\ A_{si} = \frac{W_i}{P_{si}};\ A_{qsi} = \frac{W_i}{P_{qsi}};\ q \in (m, x) \tag{3}$$

Using the first-order conditions in equations1-2, employment in production services can be expressed as a function of employment in agriculture and manufacturing:

$$L_{qsi} = \frac{(1-\beta-\phi_q) L_{qi}}{\phi_q};\ q \in (m, x)$$

The production functions for agriculture and manufacturing can be simplified as:

$$Q_{qi} = a_{qi} L_{qi}^{1-\beta} T_{qi}^{\beta}; \quad a_{qi} = A_{qi} \psi_q; \psi_q = \left[\frac{A_{qsi}(1-\beta-\phi_q)}{\phi_q}\right]^{1-\beta-\phi_q};\ q \in (m, x) \tag{4}$$

Given the CRS production technologies, and assumption that land share of income is distributed equally among the workers residing in a given location, total income in location i is defined as: $Y_i = W_i \left[\frac{L_{xi}}{\phi_x} + \frac{L_{mi}}{\phi_m} + L_{si}\right] = W_i \widehat{N}_i$ whereas $N_i = [L_{xi} + L_{mi} + L_{si} + L_{xsi} + L_{msi}]$ is the total number of workers in i.

Consumption

Consumer in each region has identical preference over consumption of three goods: agriculture, manufacturing and consumer services.

$$U = C_m^{\gamma} C_x^{\delta} C_s^{1-\gamma-\delta}$$

The utility maximization on the part of the consumer implies the following demand functions:

$$C_{mi} = \frac{\gamma y_i}{P_{mi}};\ C_{xi} = \frac{\delta y_i}{P_{xi}};\ C_{si} = \frac{(1-\gamma-\delta) y_i}{P_{si}}$$

where y_i is the income of the representative consumer in location i. Given the prices of three products, the indirect utility for each representative consumer in a region can be derived as:

$$V_i = \frac{\gamma^{\gamma}\delta^{\delta}(1-\gamma-\delta)^{1-\gamma-\delta}y_i}{P_{mi}^{\gamma}P_{xi}^{\delta}P_{si}^{1-\gamma-\delta}} \tag{5}$$

To focus better on the role of transport costs and technological change in agriculture, we adopt the following assumptions:

(i) *Technology*: There is no heterogeneity in the production technology of services across regions ($A_{si} = A_s$, $A_{xsi} = A_{xs}$, $A_{msi} = A_{ms}$) and in the location-specific factor productivity in agriculture and manufacturing ($\bar{A}_{xi}$ and $\bar{A}_{mi}$) within a region for traded goods ($\bar{A}_{xh} = \bar{A}_{xh'}$ $\forall h, h' \in H$ and so on). The location specific productivity of manufacturing and agriculture are different across regions. Specifically we assume that region H and K have higher location specific productivity in agriculture and region J has in manufacturing ($\bar{A}_{xh} > \bar{A}_{xj}$ and $\bar{A}_{mj} > \bar{A}_{mh}$ $\forall h \in H;\ j \in J$). Though there is no intra-regional heterogeneity in the location specific productivity, the ex-post total factor productivity for the same good can be different within a region depending on the strength of agglomeration externality as captured by population density of each location. For simplicity of characterization of equilibrium, we assume $\alpha_x = \alpha_m = \alpha$, though we relax this assumption later.

(ii) *Transport Costs*: The transport cost between two locations depends only on the distance between them and whether they are on the opposite sides of the river ($e^{\tau d+F}$ if they are in two different regions; and $e^{\tau d}$ if within the same region where τ is a positive constant and d is the distance between the locations). This assumption implies that transport costs are not product specific, though this assumption can be relaxed at the cost of adding more notations. Note that if F is prohibitively large, it can preclude any inter-regional trade leading to autarky. On the other hand, if F and τ are very small, then all locations across rivers will trade with each other resulting in a fully integrated economy even in the absence of a bridge. We assume that the transport cost τ and ferry cost F are in the intermediate range such that each region contains integrated and isolated subregions. This assumption allows us to describe local and regional level population and employment configuration by focusing on any pair of trading subregions since regions H and K are identical at the initial equilibrium.

(iii) *Preference:* We assume that $\gamma = \delta$ which implies that income shares of agriculture and manufacturing in the consumption bundles are equal. This means that demand heterogeneity across agriculture and manufacturing does not play any role in our analysis, and simplifies the algebra substantially.

(A.2) PRE-BRIDGE EQUILIBRIUM

A competitive equilibrium in this economy consists of a set prices (goods and factors) given endowments (land and labor) and inherent productivity differences such that (i) labor market clears locally, regionally and at the country level; (ii) land market clears at the local level, land being the immobile factor of production; (iii) equalization of utility across locations among which workers are mobile (within region in the short run and at national level in the long run). The ferry and transport costs are in the intermediate range allowing both integrated and isolated sub region within each region. The integrated sub-region in H is denoted as $H^{\blacktriangle}$ and the isolated as $H^{\triangledown}$ implying that $H = H^{\blacktriangle} + H^{\triangledown}$. Since the core region J can trade with both H and K hinterlands, the isolated region $J^{\triangledown}$ falls in the middle, while the isolated regions $H^{\triangledown}$ and $K^{\triangledown}$ are situated at the other end away from the bridge. We denote the integrated sub-region in J that trades with $H^{\blacktriangle}$ and $K^{\blacktriangle}$ by $J_H^{\blacktriangle}$ and $J_K^{\blacktriangle}$ respectively.

Equilibrium in Isolated Sub-regions

We start with characterizing the equilibrium under autarky where regions do not trade with each other (e.g. $H^{\triangledown}$). By assumptions, there is no heterogeneity in the production technology for the same good within the isolated sub-region, and for each good, production technology is characterized by CRS. Markets are competitive but trading involves positive transport costs. These assumptions deliver the following results: (i) the spatial impossibility theorem (Starret (1978)) that there is no trade within the sub-region and hence each location is characterized by autarky and produces agriculture, manufacturing and consumer services since $\phi_q = (1-\beta), q \in (m, x)$, (ii) population density does not vary across locations within an isolated subregion, (iii) the equilibrium relative price of manufacturing and agriculture does not vary across locations within a sub-region, but relative price of manufacturing is higher in the isolated sub-regions in the hinterlands, i.e., in $H^{\triangledown}$ and $K^{\triangledown}$ compared to $J^{\triangledown}$ reflecting lower productivity of manufacturing in hinterlands . The labor share employed in manufacturing does not vary across different isolated sub-regions ($H^{\triangledown}$, $K^{\triangledown}$, $J^{\triangledown}$) given the Cobb-Douglas form of the production and utility functions, as the real product wages do not vary across subregions in autarky. This provides us a clean benchmark for understanding sectoral reallocation of labor between manufacturing and agriculture in response to bridge construction.

Proof: Using the first order conditions and labor market equilibrium condition and setting demand for each product/service equal to its supply, the allocation of labor to different activities can be derived as:

$$\begin{aligned} L_{xi} &= \frac{\gamma\phi_x N_i}{1-2\beta\gamma}; L_{mi} = \frac{\gamma\phi_m N_i}{1-2\beta\gamma}; L_{si} = \frac{(1-2\gamma)N_i}{1-2\beta\gamma}; \\ L_{xsi} &= \frac{(1-\beta-\phi_x)\gamma N_i}{1-2\beta\gamma}; L_{msi} = \frac{(1-\beta-\phi_m)\gamma N_i}{1-2\beta\gamma} \end{aligned}$$

where N_i is total number of workers residing in location i. Given the labor allocation determined above, the first order conditions for land use in agriculture and manufacturing can be used to derive its distribution between these two activities as:

$$T_{xi} = \frac{T}{2}; T_{mi} = \frac{T}{2}$$

Using the first order conditions in equations 1-2, and simplified production functions and $A_{qi} = \bar{A}_{qi} n_i^{\alpha}$, the relative price in location i can be defined as:

$$\frac{P_{mi}}{P_{xi}} = \frac{a_{xi}}{a_{mi}} [\frac{\phi_x}{\phi_m}]^{1-\beta} = \frac{\bar{a}_{xi}}{\bar{a}_{mi}} [\frac{\phi_x}{\phi_m}]^{1-\beta} \tag{6}$$

where $a_{qi} = \bar{a}_{qi} n_i^{\alpha}, \bar{a}_{qi} = \bar{A}_{qi} [\frac{A_{qsi}(1-\beta-\phi_q)}{\phi_q}]^{1-\beta-\phi_q}$ and $q = x, m$. If labor shares are the same so that $\phi_x = \phi_m = \phi$, then $\frac{P_{mi}}{P_{xi}} = \frac{a_{xi}}{a_{mi}} = \frac{A_{xi}}{A_{mi}} [\frac{A_{xsi}}{A_{msi}}]^{1-\beta-\phi}$. If $\phi = 1 - \beta$, $\frac{P_{mi}}{P_{xi}} = \frac{a_{xi}}{a_{mi}} = \frac{\bar{A}_{xi}}{\bar{A}_{mi}}$.Since labor is mobile, the utility of a worker is the same regardless of her choice of location/residence.

$$\begin{aligned} V_i &= \frac{z_1 y_i}{P_{mi}^{\gamma} P_{xi}^{\gamma} P_{si}^{1-2\gamma}} = \nu = \frac{z_1 W_i}{P_{mi}^{\gamma} P_{xi}^{\gamma} P_{si}^{1-2\gamma}} \\ W_i &= \overline{v} P_{mi}^{\gamma} P_{xi}^{\gamma} P_{si}^{1-2\gamma}; \overline{v} = \frac{\nu}{z_1} \end{aligned}$$

where ν is the maximized and equalized utility level and $\overline{v} = z_1 \nu$ and $z_1 = \gamma^{2\gamma}(1-2\gamma)^{1-2\gamma}$.$\overline{v}$ is thus scaled maximized utility by workers. Substituting for P_{si}, we can solve for wage:

$$W_i^{2\gamma} = \frac{\overline{v} P_{mi}^{\gamma} P_{xi}^{\gamma}}{A_{si}^{1-2\gamma}}$$

Substituting for optimal choices of land and labor, relative price (agriculture relative to manufacturing) and wage in equation (2), population density in a location i can be expressed as:

$$n_i^{\beta-\alpha} = \frac{z_2 \bar{A}_{xh}^{\frac{1}{2}} \bar{A}_{mh}^{\frac{1}{2}} A_{sh}^{\frac{1-2\gamma}{2\gamma}}}{\overline{v}^{\frac{1}{2\gamma}}}$$

where $z_2 = [\frac{1-2\beta\gamma}{2\gamma}]^{\beta} \phi_x^{\frac{\phi_x}{2}} [A_{xs}(1-\beta-\phi_x)]^{\frac{1-\beta-\phi_x}{2}} \phi_m^{\frac{\phi_m}{2}} [A_{ms}(1-\beta-\phi_m)]^{\frac{1-\beta-\phi_m}{2}}$. Population density does not vary within isolated subregion. Price of manufacturing relative to agriculture is higher in isolated subregion $H^{\triangledown}$ compared with $J^{\triangledown}$ since ($\frac{P_{mh}}{P_{xh}} = \frac{\bar{A}_{xh}}{\bar{A}_{mh}} > \frac{\bar{A}_{xj}}{\bar{A}_{mj}} = \frac{P_{mj}}{P_{xj}}$). With population density and land endowment same everywhere within a region, employment shares of manufacturing, agriculture and services also do not vary within each isolated sub-region.

Equilibrium in Integrated Sub-regions

Assuming ferry cost is lower than productivity differences for both agriculture and manufacturing, subregion $H^{\blacktriangle}$ specializes in agriculture and $J_H^{\blacktriangle}$ in manufacturing. The effects of market integration on labor allocation in this model are due to specialization of locations (and sub-regions) according to comparative advantage. We focus on this complete specialization model for the sake of simplicity of algebra. However, the main results on intersectoral and spatial labor allocation and population density in this model carry over to a model of incomplete specialization. In a location $h \in H^{\blacktriangle}$, $\frac{(1-2\gamma)}{1-2\beta\gamma}$ proportion of total population N_h goes to the production of consumer services, but the rest of the labor goes to agriculture. Price of M at any location $h \in H^{\blacktriangle}$ is $P_{mh} = P_{mj0}e^{F_H+\tau h}$ and price of X is $P_{xh} = P_{xh0}e^{-\tau h}$, where h is the distance between the riverbank H_0 and location h in the integrated subregion. The relative price of agriculture to manufacturing $\dfrac{P_{xh}}{P_{mh}}$ decreases as one moves farther away from the riverbank and into the interior of $H^{\blacktriangle}$. Since the other hinterland K is also separated from the core by an identical river and connected by the same ferry service, the trading subregions $K^{\blacktriangle}$ and $J_K^{\blacktriangle}$ are characterized by identical equilibrium conditions, assuming that $J^{\triangledown}$ is not null. The equilibrium in this case displays the following patterns: (i) population density in an integrated sub-region decreases with an increase in distance from the river bank and the slope of population density curve with respect to distance from the riven bank is larger in absolute value if the agglomeration effect is stronger; (ii) integrated subregions in the hinterlands, i.e., $H^{\blacktriangle}$ and $K^{\blacktriangle}$ specialize in agriculture and do not produce manufacturing (goods and productions services), and integrated subregions in the core, i.e., $J_H^{\blacktriangle}$ and $J_K^{\blacktriangle}$ specialize in manufacturing and do not engage in agriculture (goods and production services); (ii) population density in the integrated core $J_H^{\blacktriangle}$ ($J_K^{\blacktriangle}$) relative to that in the integrated hinterland $H^{\blacktriangle}$ ($K^{\blacktriangle}$) increase with a higher productivity gap in manufacturing, ceteris paribus. The converse also holds, population density in integrated part of hinterlands relative to the integrated subregions of the core increases when the productivity gap in agriculture is higher.

Proof

Consider the integrated subregion in region H. Given the total population N_h at $h \in H^{\blacktriangle}$, employment in agriculture L_{xh} is equal to $\frac{2\gamma\phi_x N_h}{1-2\beta\gamma}$. Using the first order condition, the ratio of population at h relative to riverbank can be expressed as:

$$\frac{N_h}{N_{h0}} = [\frac{P_{xh}W_{h0}}{P_{xh0}W_h}]^{\frac{1}{\beta-\alpha}}$$

where N_{h0} is the population at river bank H_0 and h is the distance from riverbank. It is easy to see that $\frac{P_{xh}}{P_{xh0}} = e^{-\tau h}$ and $\frac{P_{mh}}{P_{mh0}} = e^{\tau h}$. With labor mobility equating indirect utility within the region,

$$\frac{W_{h0}}{W_h} = [\frac{P_{x0}}{P_{xh}}]^{\frac{1}{2}}[\frac{P_{mh0}}{P_{mh}}]^{\frac{1}{2}} = 1$$

Using the first order conditions along with equalization of worker's utility across regions, total population in $h \in H^{\blacktriangle}$ is:

$$N_h = e^{-\frac{\tau}{\beta-\alpha}h} N_{h0}$$

Total population in a location $h \in H^{\blacktriangle}$ not only falls with an increase in distance from riverbank, but also declines at a faster rate with an increase in agglomeration externality α. Since each location is endowed with same amount of land, this also implies that population density declines at a faster rate if agglomeration externality in agriculture is higher.

Given preference homogeneity for manufacturing and agriculture, nominal wages are equalized across regions. To see this, note that $P_{xj0} = P_{xh0}e^F; P_{mh0} = P_{mj0}e^F$. With labor mobility equating indirect utility across regions, the wage ratio at the riverbank is:

$$\frac{W_{j0}^{2\gamma}}{W_{h0}^{2\gamma}} = \frac{P_{mj0}^{\gamma} P_{xj0}^{\gamma}}{P_{mh0}^{\gamma} P_{xh0}^{\gamma}} = 1$$

Since wages within a region is also equalized, labor mobility ensures that $W_h = W_j$. Utilizing first order condition for labor use, total value of good X at h is $P_{xh}X_h$ which is in turn equal to $\frac{2\gamma W_h N_h}{1-2\beta\gamma}$.Total income at h is equal to $\frac{W_h N_h}{1-2\beta\gamma}$. Given that consumer spends γ proportion of income on X, the good market equilibrium can be written as

$$2\gamma \int_0^{H^{\blacktriangle}} W_h N_h dh = \gamma[\int_0^{H^{\blacktriangle}} W_h N_h dh + \int_0^{J^{\blacktriangle}} W_j N_j dj]$$

The goods market equilibrium implies equality of total employment $N_H^{\blacktriangle}$ and $N_{JH}^{\blacktriangle}$ and that

$$\frac{N_{h0}}{N_{J0}} = \frac{[1 - e^{-\frac{\tau}{\beta-\alpha}J^{\blacktriangle}}]}{[1 - e^{-\frac{\tau}{\beta-\alpha}H^{\blacktriangle}}]}$$

As an equal number of people live in each integrated subregion, population density depends on its length. To determine the border of trading zones, we note that relative price of import at any location $h \in H^{\blacktriangle}$ can be expressed as $\frac{P_{mh}}{P_{xh}} = \frac{P_{mj0}}{P_{xh0}}e^{F+2\tau h}$.Relative price of importable of a region (manufacturing for region $H^{\blacktriangle}$) increases as one moves farther interior from the riverbank. Using the first order conditions along with labor allocation across space, the equilibrium price ratio is determined as:

$$\frac{P_{mj0}}{P_{xh0}} = \frac{\phi_x^{1-\beta}\bar{a}_{xh}}{\phi_m^{1-\beta}\bar{a}_{mj}}[\frac{1-e^{-\frac{\tau}{\beta-\alpha}H^{\blacktriangle}}}{1-e^{-\frac{\tau}{\beta-\alpha}J^{\blacktriangle}}}]^{\beta-\alpha} \tag{7}$$

The border of the trading zone is determined by the arbitrage condition that at the border, price ratio under trade (equation 7) should be equal to autarky price ratio (equation 6). The border of the trading zone and hence lengths of trading subregions are determined by the following two equations (in log form):

$$2\tau H^{\blacktriangle} + (\beta-\alpha)[\ln(1-e^{-\frac{\tau}{\beta-\alpha}H^{\blacktriangle}}) - \ln(1-e^{-\frac{\tau}{\beta-\alpha}J^{\blacktriangle}})] = \ln\bar{a}_{mj} - \ln\bar{a}_{mh} - F \tag{8}$$

$$2\tau J_H^{\blacktriangle} + (\beta-\alpha)[\ln(1-e^{-\frac{\tau}{\beta-\alpha}J^{\blacktriangle}}) - \ln(1-e^{-\frac{\tau}{\beta-\alpha}H^{\blacktriangle}})] = \ln\bar{a}_{xh} - \ln\bar{a}_{xj} - F \tag{9}$$

Note that $J_H^{\blacktriangle} = H^{\blacktriangle}$ only if $\ln\bar{a}_{mj} - \ln\bar{a}_{mh} = \ln\bar{a}_{xh} - \ln\bar{a}_{xj}$. This is in contrast to population distribution between the two trading partners which is determined by preference parameters alone. Thus despite symmetry in preference for agriculture and manufacturing, population density in the integrated subregions in the opposite sides of the river could be different depending on productivity differences for these products. Suppose we start with $J_H^{\blacktriangle} = H^{\blacktriangle}$. Let $\Delta_{mjh} = \ln\bar{a}_{mj} - \ln\bar{a}_{mh}$.Using equations 8 and 9, we can derive the following effect of a marginal change in Δ_{mjh} as:

$$\frac{\partial J_H^{\blacktriangle}}{\partial\Delta_{mjh}} / \frac{\partial H^{\blacktriangle}}{\partial\Delta_{mjh}} = \frac{1}{e^{\frac{\tau}{\beta-\alpha}H^{\blacktriangle}}[2-e^{-\frac{\tau}{\beta-\alpha}J_H^{\blacktriangle}}]} < 1$$

An increase in $\ln\bar{a}_{mj} - \ln\bar{a}_{mh}$ increases both $J_H^{\blacktriangle}$ and $H^{\blacktriangle}$, but increases $H^{\blacktriangle}$ by more than proportionately. Given that half of total population in the integrated subregions is in $H^{\blacktriangle}$, this implies higher density of population in $J_H^{\blacktriangle}$ than $H^{\blacktriangle}$.Note also that for trade to happen between these two regions, F has to be less than $\hat{F}$, where $\hat{F} = \min\{(\ln\bar{a}_{mj} - \ln\bar{a}_{mh}), (\ln\bar{a}_{xh} - \ln\bar{a}_{xj})\}$.An increase in transport cost τ decreases both $J_H^{\blacktriangle}$ and $H^{\blacktriangle}$. Assuming $(\ln\bar{a}_{mj} - \ln\bar{a}_{mh}) > (\ln\bar{a}_{xh} - \ln\bar{a}_{xj})$,define $\hat{\tau}$ such that $H^{\blacktriangle} = H$ in equation(8). For $\tau \leq \hat{\tau}$, there will be no subregion that is isolated. The equilibrium characterized here assumes $F << \hat{F}$ and $\tau >> \hat{\tau}$.

Economy-wide Equilibrium and Worker's Indirect Utility

The labor mobility across regions links the integrated and isolated subregions throughout the country. *The spatial equilibrium with both isolated and integrated sub-regions within each region displays the following characteristics: (i) within each region, population density in integrated subregion is higher than isolated subregion, (ii) all three regions will produce all five different goods and services, regions H and K have disproportionately more employment in agriculture and region J has more manufacturing employment compared with autarky equilibrium.*

With lengths of trading regions determined in equations (8) and (9), the first order conditions along with labor mobility conditions can be combined to derive employment density in each location:

$$n_i^{\blacktriangle} = n_{vi}^{\triangledown}\overline{v}^{-\frac{1}{2\gamma(\beta-\alpha)}}e^{\frac{\tau}{\beta-\alpha}[I^{\blacktriangle}-i]}; i \in \{h, j, k\}; I^{\blacktriangle} \in \{J_H^{\blacktriangle}, H^{\blacktriangle}, K^{\blacktriangle}, J_K^{\blacktriangle}\}$$

where $n_{vi}^{\triangledown} = [\frac{(1-2\beta\gamma)}{2\gamma}]^{\frac{\beta}{(\beta-\alpha)}}\phi_x^{\frac{1-\beta}{2(\beta-\alpha)}}\phi_m^{\frac{1-\beta}{2(\beta-\alpha)}}(\bar{a}_{xi})^{\frac{1}{2(\beta-\alpha)}}(\bar{a}_{mi})^{\frac{1}{2(\beta-\alpha)}}A_s^{\frac{1-2\gamma}{2\gamma(\beta-\alpha)}}$, $n_i^{\blacktriangle}$ is density at a location $i \in h, j, k$ in integrated subregion and $n_i^{\triangledown} = n_{vi}^{\triangledown}\overline{v}^{-\frac{1}{2\gamma(\beta-\alpha)}}$ is density at location i in isolated subregion and $\overline{v}$ is the optimized utility which is equated across areas due to labor mobility. Population density at any point $i \in I^{\blacktriangle}$ is higher than what it would have been under autarky as $e^{\frac{\tau}{\beta-\alpha}[I^{\blacktriangle}-i]} > 1$.

Total population in a region can be defined as:

$$N_I = Tn_{vI}^{\triangledown}\overline{v}^{-\frac{1}{2\gamma(\beta-\alpha)}}[\frac{\beta-\alpha}{\tau}(e^{\frac{\tau}{\beta-\alpha}I^{\blacktriangle}} - 1) + I - I^{\blacktriangle}]; I \in \{H, K, J\}; I^{\blacktriangle} \in \{J_H^{\blacktriangle}, H^{\blacktriangle}, K^{\blacktriangle}, J_K^{\blacktriangle}\}$$

Holding v constant, total population in trading sub-region increases with an increase its length though the increase in length comes at the expense of a decrease in the length of isolated sub-region. However, population movement is likely to induce a change in maximized utility as well given fixed labor supply.

The maximized utility ($\overline{v}$) is determined from the economy-wide labor market clearing condition as:

$$N\overline{v}^{\frac{1}{2\gamma(\beta-\alpha)}} = T\sum\{n_{vI}^{\triangledown}[\frac{\beta-\alpha}{\tau}(e^{\frac{\tau}{\beta-\alpha}I^{\blacktriangle}} - 1) + I - I^{\blacktriangle}];\ I \in \{J, H, K\}; I^{\blacktriangle} \in \{J_H^{\blacktriangle}, H^{\blacktriangle}, K^{\blacktriangle}, J_K^{\blacktriangle}\} \qquad (10)$$

The optimized utility increases with an increase in the length of integrated sub-regions, land endowment and productivity increase (subsumed in autarky employment) and decreases with an increase in labor endowment. Sub-regions $H^{\blacktriangle}$ and $K^{\blacktriangle}$ specialize in X and $J_H^{\blacktriangle}$ and $J_K^{\blacktriangle}$ specialize in M whereas isolated subregions in all regions produce all five goods and services. As a result, employment in H and K are tilted towards agriculture and in J toward manufacturing.

Employment composition in region H can be described as:

$$N_{xH} = \frac{\phi_x\gamma[2N_H^{\blacktriangle} + N_H^{\triangledown}]}{1-2\beta\gamma}; N_{mH} = \frac{\gamma\phi_m N_H^{\triangledown}}{1-2\beta\gamma}; N_{sH} = \frac{(1-2\gamma)\overline{N}_H}{1-2\beta\gamma} \qquad (11)$$

$$N_{sxH} = \frac{\gamma(1-\beta-\phi_x)[2N_H^{\blacktriangle} + N_H^{\triangledown}]}{1-2\beta\gamma}; N_{msH} = \frac{\gamma(1-\beta-\phi_m)N_H^{\triangledown}}{1-2\beta\gamma} \qquad (12)$$

where $N_H^{\blacktriangle}$ and $N_H^{\triangledown}$ are total population in integrated and isolated subregions.

(3.3) THE EFFECTS of BRIDGE OVER the RIVER R_H

We consider the case where a bridge is constructed only over the river R_H that separates regions H and J. Construction of the bridge reduces the cost of crossing the river between H and J but does not change the ferry cost between J and K ($F_H < F_K = F$). We consider two different scenarios regarding the impacts of construction of bridge depending on labor mobility: (i) in the short-run, labor is mobile within region but not across regions; (ii) long-run when labor is mobile both across and within regions.

Short-run Effects: Labor Immobile

Absence of interregional labor mobility means that the impacts of bridge can be analyzed by focusing on regions H and J separately. We focus on region H first. A decrease in F_h decreases the price of manufacturing imported from J at location h, P_{mh} but has no direct impact on the price of agriculture P_{xh} resulting in an increase in the relative price of exportable for a location $h \in H_B^{\blacktriangle}$, where subscript B refers to variables measured in the periods after bridge construction. The change in relative price induces intersectoral labor reallocation as more locations in H switch from autarky to trading and specialize in agriculture, thus $H^{\blacktriangle} \subset H_B^{\blacktriangle}$. Proposition 1 summarizes the impacts of bridge in the immediate term when labor is immobile even within region.

Proposition 1: Assume that the isolated sub-region in the core after bridge construction is a non-null set, i.e., $J_B^{\triangledown} > 0$. In the short run when labor is immobile, a decrease in the cost of river crossing due to construction of a bridge between regions H and J leads to the following (denoting post-bridge variables with a subscript B):

(i) a decrease in employment in manufacturing ("de-industrialization") in region H and in agriculture in J;

(ii) an increase in employment share of services in regions H and J if production services are used only for inter-regional trade;

(iii) a decrease in employment share of agriculture in region H if production services are used only for inter-regional trade and $\frac{(1-\beta)}{2} > \phi_x$;

(iv) employment reallocation effect is strongest in locations that switch from autarky to trading as a result of bridge ($h \in [H^{\blacktriangle}, H_B^{\blacktriangle}]$); and

(v) no impact on population density or employment density in subregions and regions ($J_K^{\blacktriangle}, K^{\blacktriangle}, K^{\triangledown}$), not directly connected by bridge.

Proof: In the short-run, labor is immobile within and across regions. Note that $\frac{P_{mh}}{P_{xh}} = \frac{P_{mj0}}{P_{xh0}} e^{F+2\tau h}$ where $\frac{P_{mj0}}{P_{xh0}}$ stays at the pre-bridge equilibrium due to labor immobility. Setting $h = H^{\blacktriangle}$ and imposing the equality of trade and autarky price ratios at the border $h = H^{\blacktriangle}$, the immediate effect of bridge can be derived as:

$$\frac{\partial H^{\blacktriangle}}{\partial F_H}|_{SR} = -\frac{1}{2\tau} = \frac{\partial J^{\blacktriangle}}{\partial F_H}|_{SR} < 0$$

where subscript SR stands for short-run. In other words, bridge leads to an *an expansion in the integrated sub-regions, i.e.,* $H_B^{\blacktriangle} \supset H^{\blacktriangle}$, *and* $J_{HB}^{\blacktriangle} \supset J_H^{\blacktriangle}$, *and a shrinkage of the isolated subregion in both the core and periphery regions, i.e.,* $H_B^{\triangledown} \subset H^{\triangledown}$ *and* $J_B^{\triangledown} \subset J^{\triangledown}$. Because of the extension of the trading subregion, total employment and hence population in the integrated subregion increases even without labor movement. The newly integrated subregion specializes in agriculture in H and in manufacturing in J, leading to the prediction in proposition 1(i). Total employment $N_H^{\blacktriangle}$ increases as $H^{\blacktriangle}$ expands. Given that $N_H^{\triangledown} = n_{vh}^{\triangledown} \bar{v}^{-\frac{1}{2\gamma(\beta-\alpha)}}[H - H^{\blacktriangle}]$, the increase in total employment in trading subregion is

$$\frac{\partial N_H^{\blacktriangle}}{\partial F_H}|_{SR} = -\frac{\partial N_H^{\triangledown}}{\partial F_H}|_{SR} = -\frac{n_{vh}^{\triangledown} \bar{v}^{-\frac{1}{2\gamma(\beta-\alpha)}}}{2\tau} = -\frac{n_h^{\triangledown}}{2\tau}$$

An increase in $N_H^{\blacktriangle}$ due to expansion of $H^{\blacktriangle}$ leads to more employment in exportable subsector: agriculture and related production services in H and manufacturing and related services in J. Note also that share of consumption services in total employment does not change due to a decrease in F_H as a constant proportion of income is spent on this which is produced under CRS. If production related services are required regardless of whether engaged in inter-regional trade or not, then impact of bridge on services share is ambiguous. It increases services in region H if $\phi_x < \phi_m$, has no impact if $\phi_x = \phi_m$ and negative impact if $\phi_x > \phi_m$.

Suppose production related service is needed only if a location is engaged in inter-regional trade. This means $\phi_x = (1 - \beta)$ under autarky and $\phi_x < (1 - \beta)$ under trade. The expansion of inter-regional trading subregion in this case unambiguously increases share of production services in total employment. The change in share of agriculture in employment in location h that switched from autarky to trade as a result of bridge is:

$$\partial(\frac{N_{xh}}{N_h}) = \frac{\gamma}{1 - 2\beta\gamma}[2\phi_x - (1 - \beta)]$$

The share of agriculture in total employment at h before bridge was $(1 - \beta)$. After the the bridge, the share is $2\phi_x$ where $2(1 - \beta - \phi_x)$ is the share of production related services. Agriculture's share in employment decline if $\phi_x < \frac{(1-\beta)}{2}$. If after the reduction of F_H,all of the isolated subregion becomes integrated, manufacturing will disappear from region H. Note also that employment shares in areas that were either integrated before the bridge or remained isolated after the bridge are not affected by a reduction in F_H. Finally, because the cost of crossing the river between J and K are unaffected, and there is no labor mobility, employment composition and population distribution in region K and subregion $J_K^{\blacktriangle}$ remain unaffected by a reduction in F_H.

Long-run Impacts: Labor mobile between regions

In the long run, labor is mobile across regions. The lower price of imported good due to bridge opening increases the maximized utility for the representative consumer at any location $i \in I_B^{\blacktriangle}, I \in H, J_H$, since $\frac{\partial \bar{v}_i^{\blacktriangle}}{\partial F_H}|_{SR} = -\gamma\bar{v} < 0$ in the integrated subregion.This leads to population reallocation across all regions.

Proposition 2: In the long run, a decrease in the cost of river crossing due to the construction of a bridge between regions H and J leads to the following effects:

(i) a further extension of $H_B^{\blacktriangle}$ if $H^{\blacktriangle} > J^{\blacktriangle}$ in initial equilibrium and vice versa;

(ii) reduces the population density in the region that did not receive the bridge (region K) and increases the population density in both the connected integrated regions (H, J_H), more so in the center if $H^{\blacktriangle} > J^{\blacktriangle}$ in initial equilibrium and/or agglomeration externality in manufacturing is larger;

(iii) Integrated areas (new and old) experience higher productivity in their exportables due to technological externality;

(iv) The effects on employment specialization is more pronounced in the long run compared with short-run due to population mobility and positive productivity effects and

(v) similar to short-run effects, employment effects are strongest at the extensive margin of pre-bridge integrated subregion.

Proof: With intra-regional labor mobility, population density in both regions are now affected which in turn affects border of trading subregions as well. Using equations (8) and (9) above, the effect of an increase in F_H on the lengths of trading zones are defined as:

$$\begin{aligned}
\frac{\partial J_H^{\blacktriangle}}{\partial F_H}|_{LR} &= -\frac{[1-e^{-\frac{\tau}{\beta-\alpha}J^{\blacktriangle}}]}{\tau[(1-e^{-\frac{\tau}{\beta-\alpha}J^{\blacktriangle}})+(1-e^{-\frac{\tau}{\beta-\alpha}H^{\blacktriangle}})]} < 0 \\
\frac{\partial H^{\blacktriangle}}{\partial F_H}|_{LR} &= -\frac{(1-e^{-\frac{\tau}{\beta-\alpha}H^{\blacktriangle}})}{\tau[(1-e^{-\frac{\tau}{\beta-\alpha}J^{\blacktriangle}})+(1-e^{-\frac{\tau}{\beta-\alpha}H^{\blacktriangle}})]} < 0 \\
\frac{\partial J_K^{\blacktriangle}}{\partial F_H}|_{LR} &= \frac{\partial K^{\blacktriangle}}{\partial F_H}|_{LR} = 0
\end{aligned}$$

The total change in integrated subregions $\frac{\partial(J_H^{\blacktriangle}+H^{\blacktriangle})}{\partial F_H}|_{LR} = -\frac{1}{\tau}$. $|\frac{\partial H^{\blacktriangle}}{\partial F_H}|_{LR}| > \frac{1}{2\tau} = |\frac{\partial H^{\blacktriangle}}{\partial F_H}|_{SR}|$ if $H^{\blacktriangle} > J_H^{\blacktriangle}$ and that $|\frac{\partial J_H^{\blacktriangle}}{\partial F_H}|_{LR}| < |\frac{\partial J_H^{\blacktriangle}}{\partial F_H}|_{SR}|$.

A reduction in F_H does not affect trading cost between regions K and J directly but real wages are higher in *($H^{\blacktriangle}$, $J^{\blacktriangle}$)* due to bridge. As employment density responds inversely to real wage, population density in K falls and that in integrated subregions *($H^{\blacktriangle}$,, $J_H^{\blacktriangle}$)* rises. The changes in real wage/optimized utility in long run for region H can be derived as:

$$\frac{\partial \bar{v}}{\partial F_H}|_{LR} = \frac{2\gamma\bar{v}\tau N_H^{\blacktriangle}}{N}[\frac{\partial H^{\blacktriangle}}{\partial F_H}|_{LR} + \frac{\partial J_T^{\blacktriangle}}{\partial F_H}|_{LR}] = -\frac{2\gamma\bar{v}N_H^{\blacktriangle}}{N}$$

Thus maximized utility in the connected subregions decreases while that in unconnected subregions increases in the long run in response to bridge. Total employment and thus population density in K declines:

$$\frac{\partial N_K}{\partial F_H} = \frac{\partial N_K}{\partial v} * \frac{\partial \bar{v}}{\partial F_H} = \frac{N_K}{2\gamma\bar{v}(\beta-\alpha)} * \frac{2\gamma\bar{v}N_H^{\blacktriangle}}{N} = \frac{N_K N_H^{\blacktriangle}}{(\beta-\alpha)N} > 0$$

It is interesting to see how total population in isolated subregion of H ($N_H^{\triangledown} = n_{vh}^{\triangledown}\bar{v}_h^{-\frac{1}{2\gamma(\beta-\alpha)}}[H - H^{\blacktriangle}]$) responds to a reduction in F_H.

$$\begin{aligned} \frac{\partial N_H^{\triangledown}}{\partial F_H} &= -n_{vh}^{\triangledown}\bar{v}_h^{-\frac{1}{2\gamma(\beta-\alpha)}}\frac{\partial H^{\blacktriangle}}{\partial F_H} - \frac{N_H^{\triangledown}}{2\gamma(\beta-\alpha)\bar{v}_h}\frac{\partial \bar{v}_h}{\partial F_H} \\ &= -n_{vh}^{\triangledown}\bar{v}_h^{-\frac{1}{2\gamma(\beta-\alpha)}}\frac{\partial H^{\blacktriangle}}{\partial F_H} + \frac{N_H^{\triangledown}}{N(\beta-\alpha)} > 0 \end{aligned}$$

The first term depicts the decrease in population in isolated region due to an expansion of integrated region, and second term shows the decrease due to an increase in $\bar{v}$ that caused labor to move out of isolated subregion. It follows from above analysis that all subregions not directly connected by the bridge will experience a decline in population as well as its density (represented by the second term) with a reduction in F_H.

For integrated subregions connected by bridge, since $\frac{N_H^{\blacktriangle}}{N} < \frac{1}{2}$, $|\frac{\partial \bar{v}_i^{\blacktriangle}}{\partial F_H}|_{SR}| > |\frac{\partial \bar{v}}{\partial F_H}|_{LR}|$, population density will be higher in the longer run. From trade balance condition, it follows that increase in total population in the integrated subregions ($H^{\blacktriangle}$ and $J_H^{\blacktriangle}$) are equal to each other. This in turn implies $|\frac{\partial n_{JH}^{\blacktriangle}}{\partial F_H}|_{LR}| > |\frac{\partial n_{JH}^{\blacktriangle}}{\partial F_H}|_{SR}|$ if $H^{\blacktriangle} > J_H^{\blacktriangle}$. In other words, impacts on employment shares in treatment hinterland and population density in core are larger in the longer run compared with short-run. Proposition (iii) follows from the fact that observed total factor productivity in traded goods are positive functions of inherent local productivity and population density. An increase in population density is reflected in higher productivity in both tradable goods. The change in employment structure is also more prominant at the margin of integrated subregions because bridge opening not only increases density at each point in the integrated sub-regions but also extends its border. The bordering areas used to produce a diversified portfolio of products and services before bridge and switch to specialized portfolio after the bridge. The model used a static set-up and assumed away migration cost. In a more general model where migration involves cost and staggered learning (e.g. network externality), the combination of population movement and technological externality can also shift the trajectory of growth of key variables such as density and real wage.

The $3x3$ model developed here can be utilized to contrast predictions from alternative $2x2$ (two regions and two products: manufacturing and agriculture) model. Predictions from classical trade model can be derived by setting $\alpha_x = \alpha_m = \alpha = 0$ and $K = 0$. If $H^{\triangledown}, J_H^{\triangledown} > 0$, then this classical model predicts an increase in agriculture's share in employment in H and manufacturing's share in J. On the other hand, if both regions were fully integrated before bridge ($H^{\triangledown} = J_H^{\triangledown} = 0$), then opening of bridge has no impact on employment composition or population density though it improves welfare (increases $\bar{v}$). For predictions from a simple core-periphery model, we set $H^{\triangledown}, J_H^{\triangledown} > 0; K^{\triangledown} = K = 0$ and $\alpha_x = 0, \alpha_m > 0$. In other words, agglomeration externality is present only in manufacturing and inter-regional trade was not feasible before bridge construction. This core-periphery set up predicts an increase in manufacturing share and population density in J and a decrease in the same in region H. Having the second hinterland in the model allows population density in H to increase in contrast with classical and core-periphery models. While having a non-traded consumption services does not change composition of employment due to homothetic preference, presence of production service that are needed in case of inter-regional trade can actually lead to a decline in agriculture in region H even though it specializes in agriculture.

Two more issues: (i) *Presence of autarkic region in J*: If autarkic region is not there, then as expansion of trade with H in response to a reduction in F_H causes a reduction of trade between J_K and K. Implications for employment shares are: higher share of manufacturing and lower share of services in K relative to H. The short-run results are not consistent with this.

(ii) *Costly Migration*: Migration is assumed to be costless and instantaneous and there is no time lag in reaping of agglomeration economies. Suppose agglomeration depends on last period's population density and migration is costly. Consider three different periods: period 0 which is right after bridge opening but before any population movement, period 1 when there is population movement but agglomeration effects have not been realized and period 2 when agglomeration effects have taken force. One way to see the impacts during different period is to see the impacts on population density at riverbank ($n_{h0}^{\blacktriangle} = n_{vi}^{\triangledown}\bar{v}^{-\frac{1}{2\gamma(\beta-\alpha)}} e^{\frac{\tau}{\beta-\alpha}H^{\blacktriangle}}$). Note that immediately following the reduction in cost of river crossing, maximized utility for the representative consumer in connected integrated region increases due to a fall in price of its import: $\frac{\partial \bar{v}_i^{\blacktriangle}}{\partial F_H}|_{SR} = -\gamma\bar{v}$. However, population movement in the long-run increases maximized utility of all subregions except two connected integrated subregions. The two connected integrated subregions experience a decline in maximized utility from its short-run level immediately following bridge opening and the net change in $\bar{v}$ for these treatment subregions is equal to ($\frac{\partial \bar{v}_i^{\blacktriangle}}{\partial F_H}|_{LR} = \frac{\gamma\bar{v}(N-2N_H^{\blacktriangle})}{N}$). The long-run increase in density at the bridge location can be derived as:

$$\frac{\partial n_{h0}^{\blacktriangle}}{\partial F_h} = \frac{n_{h0}^{\blacktriangle}}{2(\beta-\alpha)}[2\tau\frac{\partial H^{\blacktriangle}}{\partial F_H}|_{LR} - \frac{N-2N_H^{\blacktriangle}}{N}]$$

Now change in density overtime can be defined as:

$$\text{Period 0:} \quad \frac{\partial n^{\blacktriangle}_{h0}}{\partial F_h} = 0$$

$$\text{Period 1:} \quad \frac{\partial n^{\blacktriangle}_{h0}}{\partial F_h} = \frac{n^{\blacktriangle}_{h0}}{2\beta}[2\tau\frac{\partial H^{\blacktriangle}}{\partial F_H}|_{LR} - \frac{N-2N^{\blacktriangle}_H}{N}]$$

$$\text{Period 2} \quad : \quad \frac{\partial n^{\blacktriangle}_{h0}}{\partial F_h} = \frac{n^{\blacktriangle}_{h0}}{2(\beta-\alpha)}[2\tau\frac{\partial H^{\blacktriangle}}{\partial F_H}|_{LR} - \frac{N-2N^{\blacktriangle}_H}{N}]$$

$$|\frac{\partial n^{\blacktriangle}_{h0}}{\partial F_h}|_{t=1} \quad < \quad |\frac{\partial n^{\blacktriangle}_{h0}}{\partial F_h}|_{t=2}$$

Since population density at any point $h \in H^{\blacktriangle}$ is $n^{\blacktriangle}_h = n_{h0}e^{-\frac{\tau}{\beta-\alpha}h}$, the entire curve describing population density shifts upward as population starts to move. But the shift is smaller in period 1 ($\frac{1}{\beta} < \frac{1}{\beta-\alpha}$) as productivity effects are yet to be realized. With time lag in productivity enhancement, a series of shifts may be required to reach the long run equilibrium effect as described in period 2. The presence of productivity effects in agriculture and manufacturing provides additional sources of deviations between short- and long term effects. While agglomeration in this model is driven by population density, an alternative model can be developed where technology adoption due to better market access drives population movement and thus acts at the primary source of deviation between short-term and longer term effects. In practice, it is likely that both technology adoption and agglomeration economies operate simultaneously reinforcing each other.