Dams and Intergovernmental Transfer: Are Dam Projects Pareto Improving in China?

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Abstract: Large-scale dams are controversial public infrastructure projects due to the unevenly distributed benefits and losses to local regions. The central government can make redistributive fiscal transfers to attenuate the impacts and reduce the inequality among local governments, but whether large-scale dam projects are Pareto improving is still a question. Using the geographic variation of dam impacts based on distances to the river and distances to dams, this paper adopts a difference-in-difference approach to estimate dam impacts at county level in China from 1996 to 2010. I find that a large-scale dam reduces local revenue in upstream counties significantly by 16%, while increasing local revenue by similar magnitude in dam-site counties. The negative revenue impacts in upstream counties are mitigated by intergovernmental transfers from the central government, with an increase rate around 13% during the dam construction and operation periods. No significant revenue and transfer impacts are found in downstream counties, except counties far downstream. These results suggest that dam-site counties benefit from dam projects the most, and intergovernmental transfers help to balance the negative impacts of dams in upstream counties correspondingly, making large-scale dam projects close to Pareto improving outcomes in China.

Keywords: Large-scale Dams, Distributive Impacts, Intergovernmental Transfers, China

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1 Introduction

Many countries invest heavily on infrastructure projects to stimulate economic development and reduce poverty. The annual infrastructure investment in China amounted to more than 20% of national gross domestic product (GDP) in the past decade, covering public and private infrastructure projects on energy, transportation, primary natural resources, public facilities, hydrological and agricultural infrastructures. These projects bring uneven impacts to local regions, with benefits like economic production, increasing employment, lower transaction and transportation cost for the society and spillover benefits to other industries[1] and losses like involuntary migration, crowding-out traditional industries and social structure change[2] etc. Governments use redistributive intergovernmental transfers to balance the economic performances of local governments. Given the coexistence of benefits and losses caused by the infrastructure projects, is the governmental redistribution system effective to mitigate the negative impacts? Are infrastructure projects Pareto improving under the governmental redistribution system? Are regions equally benefitting from the infrastructure projects?

I particularly focus on large-scale dams in China, i.e. dams with height above 100 meters to answer the above questions, for three considerations. First, large-scale dams bring huge economic impacts to a wide range of areas. There are 142 large-scale dams, i.e. dams with height above 100 meters in China by 2010, contributing to 40% of total hydropower generation capacity and 44% of water storage capacity [3]. Second, dam impacts show significant geographic characteristics. Once the dam wall divides a river basin into three sections, upstream, dam-site and downstream regions, each region will be exposed to different benefits and risks from the same dam project, making the uneven impacts observable at administrative government level. Third, most large-scale dam projects are approved by the central government (Ministry of Water Resources) in China, which provides a social and economic context with more concentrated governmental involvement in the dam decision making and intergovernmental redistribution.

To analyze the governmental redistributive system, I first introduce a simple fiscal federalism model representing the multi-level governments' decision making process on intergovernmental transfers and infrastructure approvals, following the model setup for intergovernmental fiscal relationship by Zou (2012) and Slack (1980). The model implies that no region should be worse-off from a publicly approved dam project and negative revenue impacts will be mitigated by the intergovernmental transfers if the redistribution system is effective. The total economic impacts of dam projects on a local government

[1]See Aschauer (1989), Munnell (1990), Haughwout (1998) , Fernald (1999) and Banerjee et al. (2012) for transportation infrastructures, Greenstein and Spiller (1995) and Nadiri et al. (2009) for telecommunication infrastructures, De Long and Summers (1991) for other types of infrastructures.

[2]See Brocker et al. (2010) and Meijers et al. (2012) for related researches.

[3]Hydropower contributes to around 16% of total power generation in 2010 in China.

are composed by the local revenue impacts and external transfers impacts. Following this framework, I also provide the first empirical analysis on governmental redistribution mechanism reflected from the fiscal transaction for large-scale dam projects, with analysis unit at county level in China. Most of the current literatures on empirical economic impact estimates of dam projects are about the overall economic impacts in terms of economic production or income to a region(Duflo and Pande, 2007, Strobl and Strobl, 2011, Hansen et al., 2009, Chakravarty, 2011 and Lipscomb et al., 2011). This paper takes an additional step to separate the local revenue and external transfer effects from dam projects, besides the overall economic impacts.

The paper covers 136 large-scale dams after the crosscheck of officially reported dam location and Google Earth images. These dams normally serve multiple functions, including hydropower generation, flood control, irrigation, navigation, water supply and tourism. The overall economic impacts of a dam on a specific region depends strongly on the relative distance between the region and the dam and the perpendicular distance between the region and the river. Upstream areas are subject to inundation risks and water use restrictions, as well as irrigation, navigation and tourism benefits. Dam-site areas where the dam is located are subject to electricity generation benefits, inundation and pollution risks. Downstream areas benefit from reduced flooding risks and irrigations, while they are also subject to reduced water flow and higher drought risks. The perpendicular distance to the river also matters for the impacts on a region. Most of the dam impacts, such as irrigation, flood control, hydropower generation and inundation, rely on the water flow[4], areas located close to the river will be impacted by the hydrological changes more than areas further away.

Using geographic variation of dam impacts, I adopt a difference-in-difference(DID) approach to explore the differences between counties directly impacted by dams as the treatment counties and similar counties not impacted by dams as the control counties, before and after the dam construction to get unbiased estimates of dam impacts in the construction and operation periods. I obtain estimates separately for three main areas along the river, upstream, dam-site and downstream regions categorized by hydrological flow information. Because the DID approach uses the information of existing distribution of dam locations, the estimates are robust to the fact that dam locations may be not exogenous to the economic performance.

I define treatment counties as counties with geographic centroids located within 20km away from the river, and control counties as counties with geographic centroids located slightly further away. Because upstream counties are normally wider and larger than downstream counties, upstream control counties are defined as these located in the band

[4]The paper doesn't include the analysis on power supply beyonds electricity generation. Because the electricity supply destination are mostly large regions, such as East China or North China, depending on contracts for individual dams, control and treat counties are likely to enjoy similar electricity supply benefits. the difference-in-difference estimates will not capture the electricity supply benefits.

of 20km to 100km away from the river, while downstream control counties are defined as these located in the band of 20km to 50km away from the river. Considering that the average size of county in China is around 400 square kilometers, treatment counties are almost the closest layer of counties along the river, while the control counties are just next to the treatment counties, but slightly away from the river. To link the counties and dams, I assume that the nearest dam impacts treatment counties the most, which is empirically verified. Control counties are used repeatedly for multiple dams. This categorization on countries also provides a group of treatment and control counties linking to the same dam for all locations. Following this definition, the treatment and control counties show similar pre-dam trends for most economic and demographic variables, meeting the assumption for DID estimation.

The first set of results is on governmental fiscal revenues, which covers tax and fee revenue collected from the local administrative region. The results indicate that dam-site counties significantly benefit from dam projects, while upstream counties significantly get harmed. The revenue impacts of dam operation is larger than that of dam construction, considering that dam only functions partially in the construction period. A large-scale dam increases the revenue in the dam-site counties by 12.9% during the dam construction period and 19.9% during the dam operation period. Upstream counties, however, suffer a 16.5% decrease in per capita governmental revenue during the operation period and 7.5% decrease during the construction period. Downstream counties are not significantly impacted. The negative impacts in the upstream counties are not all from inundation and resettlement losses, but also potentially from other changes, such as long-term social and economic disruptions and water use restriction in the upstream. Most of the revenue impacts to the dam-site counties are from hydropower generation benefits.

The second set of results is on net intergovernmental transfers received by local county governments. Both the upstream and dam-site counties receive more transfer. However, the transfer effect is much larger in the dam construction period than that in the dam operation period. Per capita transfer into upstream counties increases by 13.6% during the construction period and 6.7% insignificantly during the operation period. The transfer to dam-site counties increase by more than 16% in both periods. The transfer effect in downstream counties is not significant. Increases in net transfers into upstream counties sufficiently mitigate the negative revenue impacts in the upstream counties.

Both the revenue and transfer impact estimates show geographic heterogeneities. The closer a county is to a dam, the larger the impacts will be. Counties located within 200km away from the dam along the river are subject to the largest distributive impacts. Counties in the far downstream suffer a loss in total revenue and agricultural yield. The impacts are also heterogeneous for the designed purposes of dams. Hydropower dams bring larger distributive impacts than irrigational dams.

When combining the changes in governmental revenue and net transfers, the results indicate that large-scale dam projects in China are close to the Pareto improvement outcomes in the perspective of governmental economic performance. However, the benefits distribute unevenly. Local dam-site counties capture most of the benefits. Downstream counties get slightly worse off, but the effects are not statistically significant. The results on the macro economic performance of GDP show similar patterns, except that upstream counties also getting worse off. This indicates that even though the transfers attenuate the negative impacts to a certain extent, the magnitude of transfers to the upstream and downstream counties are smaller than the optimal level. The uneven economic impacts on different regions imply that the central government put a larger decision weight on the dam-site counties comparing to others when making fiscal redistributions. It reveals that counties with the geography suitable for building dams have larger decision weights.

The above results are robust to subsample analysis and different estimate specifications. Falsification tests verify the credibility of the classification of treatment and control counties, and classification of time periods to capture the impacts. The main results on dam-site county benefits and upstream compensations are robust to the data collapse methodology proposed by Bertrand et al. (2004) to correct the serial correlation concerns caused by DID analysis on long time series.

To my knowledge this is the first paper not only studying the economic impacts, but also separating the internal governmental revenue and external governmental redistribution impacts from large-scale dams in China. The paper contributes to the large literatures on dam impacts (Duflo and Pande, 2007, Strobl and Strobl, 2011, Hansen et al., 2009, Chakravarty, 2011 and Lipscomb et al., 2011), infrastructure and development (Aschauer, 1989 and Banerjee et al., 2012) and intergovernmental transfers (Sole-Olle and Sorribas-Navarro, 2008 and Zou, 2012). The findings can provide policy implications on the welfare impacts of hydropower dams and intergovernmental redistribution decision making in China.

The following part begins with an introduction on dams and intergovernmental transfers in China. Section III shows a theoretical model for intergovernmental transfer decision process of infrastructure projects. Section IV discusses the data collection for empirical analysis. Section V introduced the DID approach. Section VI presents the results, robustness analysis and policy implications of the results. Section VII concludes.

2 Dams and Intergovernmental Transfer in China

There have been 24,119 dams built in China by 2008, accounting to more than 50% of the dams in the world. Even though the overall dam construction speed has slowed down since the 1990s', the speed of large-scale dam construction, i.e. dams with height above 100 meters has accelerated[5](see Table 1). On average, there were 1.3 large-scale dams built every year before 1988. The numbers rose to 4.8 between 1989 and 2005 (CHINCOLD, 2008). More large dams will be built in the next 10 years[6]. Large-scale dams are strategically important for renewable energy generation and water regulation in China.

In the following section, I first introduce large-scale dam projects in China. Then I explain the economic benefits and losses related to these dams. Following that, I describe the intergovernmental transfer system in China.

2.1 Large-scale Dams in China

In China, dams are classified into 6 categories, large I, large II, medium, small I, small II and others[7] based to the scale of the reservoir. The decision making process differentiates for dams of different categories. Higher-ranked dams require approval from higher level of governments. 98% of dams with height above 100 meters are classified as large I hydrological projects, which need the approval from the central government. Dams with lower heights and smaller reservoirs are more likely to be approved by provincial or prefectural governments. Besides that, even though there is no official regulations, dam above 100 meters is a category routinely reported in the dam statistics and local economic reports. This may provide a small nudging effect for the decision makers to propose dam projects with height above 100 meters instead of below when the height is close to 100 meters. This phenomenon may occur when local governments use the dam projects to signal local governor performances. Figure 4 plots the distribution of dam heights for new dams above 30 meters from 1996 to 2003. It shows that when the dam height is close to 100 meters, they are more likely to exceed 100 meters than below it. In the rest of the paper, dams above 100 meters will be called as large-scale dams. By focusing on this specific category of dams, the analysis can provide implications on redistribution mechanisms of central-approved large dam projects.

Large-scale dams normally serve multiple functions, including hydropower generation, irrigation, flood control, water supply, navigation and tourism. To meet these functions, a dam wall is built on the river, storing water in the reservoir behind the wall and releasing water downstream for specific purposes. The main dam operation scheme is to decide when and how much to store and release water. Most dams have a net storage in the dry

[5]The technology development in arch and buttress dams makes it possible to use less concrete and soil for construction of larger and taller dams.

[6]The installed hydropower capacity is expected to reach 320 GW in 2020, doubling the 2008 level according to the midterm and longterm development plan for renewable energy (NDRC, 2007). More than 100 GW will be from dams above 100 meters.

[7]Large I projects: reservoir> 1 billion cubic meters; Large II projects: 0.1-1 billion cubic meters; Medium projects: 10-100 million cubic meters; Small I projects: 1-10 million cubic meters; Small II projects: 0.1-1 million cubic meters; and others.

winter and early spring, and then a net release in the late spring and early summer to prepare for the summer flood.

On average, a large-scale dam costs around 1 billion CNY (140 million US Dollar) in the 2002 price level. The average dam construction period is around 7 years. These dams are mostly co-financed by the state-owned electricity company, financial institutions, the central government and local governments, with most of the investments from companies and financial institutions[8].

The approval process of large-scale dam projects follows a bottom-up structure, requiring proposals from local governments and approval by the central government. First, regional governments or the river basin committee frame the five-year plan of hydropower development in the river basin, guided by the national hydrological infrastructure development plan formed by the central government covering the goals of hydropower capacity and renewable energy proportion. Once the regional five-year plan is approved by the state council, local electricity companies, mostly state-owned, will submit project proposals, including the information of dam site choice, technological and initial feasibility study reports. Third, the central government approves the project proposal, and then the construction work can begin[9]. Local governments have limited decision power on the location and design of dams.

In addition to the governments' direct involvement in approving and investing on dam projects, they also have the administrative authority to make regulations and policy guidelines, such as environmental protection regulations on water use distribution. There have been environmental regulations restricting polluting industry development in the upstream to protect the water quality in reservoir, and guidelines on water use privilege if there were droughts or floods(MEP, 2008 and MWR, 2005). Even though the exact economic impacts of these regulations are difficult to be quantified, I expect to capture part of the impacts from overall economic outcomes.

2.2 Benefits and Losses from Large-scale Dams

By changing the hydrological cycle of the river, dams impact areas along the river differently depending on the relative location of the local county and the dam. The dam wall divides the whole river basin into three sections, upstream, dam-site and downstream regions. Upstream regions are the areas behind the dam wall. It is also called the catchment region, where the reservoir will be located and where the storage water will be from. Dam-site regions are the areas where dam is located and where the construction work

[8] For example, Ertan Dam located in the upstream of Yangtze was financed by State Development Investment Corp and Sichuan Investment Energy Corp at the proportion of 52:48. Three Gorges Dam was financed by the Three Gorges Construction Fund sponsored by the central government, Three Gorges Company and the electricity revenue after 2003, loans from China Development Bank and the Three Gorges Bond.

[9] Yangliuhu Dam is the only one that was disapproved by the central government.

occur. Downstream regions are areas where the reservoir water flow to, also called the command region. Large-scale dams often serve multiple functions.

Hydropower generation is one of the main functions from large-scale dams. Most of the power generation benefits go to dam-site regions, including tax revenue increase and potential increased job opportunities. Dam construction work can bring infrastructure improvement benefits, such as roads, telecommunication, sanitation accesses. But these benefits are also mainly restricted to dam-site regions. Even though electricity provision is believed to be one of the social benefits due to the low hydropower costs[10], it will not be included in the benefit analysis of this paper. One reason is that the specific benefiting region of power provision is difficult to be identified. The electricity benefits can spread to the whole nation or a major part of the nation through the grid system. Most of the large-scale power plants in West China[11] are now contracted to serve East China[12] under the national policy of "West-East Electricity Transfer" since 2001[13]. The power provision benefits spread quite evenly in the hydropower serving region. So the power provision benefits are not included in this paper, since it mainly targets on the unevenly distributed benefits from dams.

Water supply is another important function for dams, including water supply for irrigation, industrial and household uses. Irrigational benefits can extend to nearby downstream regions and nearby upstream regions following the canal system. Around 20% of the total irrigational regions are irrigated by dams and reservoirs in China (Zhou, 1997). Most of the main dam-irrigated cropped regions are in Yellow River and Yangtze River basins close to the dam sites. Duflo and Pande (2007) and Hansen et al. (2009) reported positive impacts on downstream agricultural yield from dam irrigation in India and US.

Flood control is also a main dam function, but mainly benefiting downstream regions. By regulating water flow through dam storage and release, dams can reduce flooding risk of the whole downstream regions in the flooding season. Other benefits of dam projects include navigation in the dam-site and upstream region, and tourism development in the local and upstream region. By lifting water level in the reservoir, the vast water body can support longer navigation route, reducing navigation risks.

Dams projects are also associated with negative impacts, including inundation, involuntary-migration, water flow change and stricter water regulations. Due to water storage in the reservoir, areas closely behind the dam are subject to inundations. People in dam-site

[10] Hydropower electricity is generally cheaper than electricity generated from coal plants. So areas served with hydropower electricity benefit from lower energy cost.

[11] Around 60% of large-scale dams are located in the western provinces, like Guizhou, Sichuan, Yunnan and Guangxi.

[12] This is the region with most economic activities in China. Power shortage generally exists in this region.

[13] For example, Longtan Dam provides 30% of the electricity generated to the local grid system and 70% to Eastern China, while the Three Gorges Dam provides all the electricity generated to Eastern China.

counties suffer from involuntary migration and asset losses. There have been more than 10 million people affected by involuntary resettlement caused by dams since 1950s. For Three Gorges Dam specifically, around 1.4 million people migrated because of the dam impacts according to the official report (Heming et al., 2001). Even though people are compensated fully or partially for the assets losses and livelihood changes, social and non-monetary environmental impacts are rarely compensated, such as damages to the social network and social capital accumulation(Cernea, 2000).

Large-scale dam projects can also bring environmental, hydrological and social changes. Hydrological cycle in the river basin will be disrupted, reflected from decreased water speed, shrinking water flow and decreased sediment delivery in downstream regions. But whether the impacts are benefits or damages for the economic production, or for agriculture specifically is ambiguous, especially when the environmental impacts occur simultaneously with irrigation and inundation functions(Yang et al., 2008). Disease burden may increase due to the change of landscapes caused by the inundation. The large reservoir surface in the dam-site and upstream region may increase the spread of mosquito-borne infectious disease, such as malaria (Chakravarty, 2011). There are also concerns about water pollution in the upstream and dam-site areas due to the accumulated wastes behind the dam wall. Large-scale dams may impact the spawning and growth of fisheries in the downstream regions, due to changes in water flow, water temperature and migration blockage(Xie et al., 2007).

Besides geographic heterogeneity on upstream, dam-site and local regions, dam impacts also show temporal heterogeneity, since the dam construction periods range more than several years. Dam construction and operation may cause different impacts. Dam construction bring negative impacts such as displacement and inundation, and positive impacts such as dam-related infrastructure construction and part of the dam functions. However, the main benefits from dam functions happen in the dam operation periods, including power generation, irrigation, flood control, water supply, navigation, tourism and fishing. Dam operation may bring negative impacts such as hydrological and fishery changes in the river. Some impacts occur both in the construction and operation periods, including pollution control and land conservation in upstream regions, social capital loss from involuntary migrations. By analyzing dam impacts in two periods separately, the temporal heterogeneity will be captured.

2.3 Intergovernmental transfer in China

The current intergovernmental transfer system in China formed in 1994 under the Tax Sharing Scheme (TSS), which shaped the vertical fiscal relationship between the central and local governments. It empowers the central government to collect certain categories of taxes or share several tax revenues with the local governments. The central government can make fiscal intergovernmental transfers to local governments for economic development and revenue redistribution purposes. Transfers often take the forms of tax return, subsidy, general transfer and special transfer for specific projects. Tax return is used to encourage investment in certain region or certain industry, for example, special development zones. General transfer is used to narrow down the gap between local expenditure and fiscal capacity. There are also transfers targeting at specific projects on infrastructure investment, agriculture, science and technology development, education and subsidy transfers for poor regions, minority ethnic regions, urban areas and natural disaster relief.

The magnitudes of transfers to a county differentiate for various types of transfers. Most transfers follow implicit formulas, mostly based on the population needing the service, fiscal deficits of local governments or ethnical composition. For instance, transfer for agriculture and rural tax reform was distributed according to the reported number of rural people and agricultural cropping areas. However, some other special transfers are more flexible, largely depending on the local needs, instead of a constant pre-defined formula, such as transfers for infrastructure construction and disaster relief. These transfers are more likely to be impacted by the local governments' project proposals, political bargaining power and historical transfer magnitudes.

For dam projects specifically, related intergovernmental transfers include tax return, special transfer for dam project construction, special transfer for reservoir protection, special transfer for water source protection, special transfer for key geographic regions, special transfer for infrastructure construction besides dams, general transfer and subsidies for fiscal deficits caused by involuntary migration, agricultural impacts or other economic impacts. New dam projects may change the intergovernmental transfer amount through multiple ways. First, general transfers may change due to dams revenue impacts and population changes, since the formula for general transfers includes elements such as fiscal deficit ratio, population size and population with special demands. Second, special transfers may be impacted because of dam related economic activities, such as dam-related infrastructure construction, reservoir protection, upstream soil and land conservation, agricultural irrigations and fisheries etc.

For local governments, total fiscal resources are composed by the internal tax revenue and external transfers. Intergovernmental transfers reflect the fiscal redistribution from upper-level governments. The transfer here are mainly governmental fiscal transfers to balance fiscal capacity of local governments. Even though they play a role of attenuating the revenue losses of local governments, private compensations made by dam companies [14] for asset loss, resettlement and migrations are not included in the transfers. So the separation of internal and external revenue sources makes it possible have a better un-

[14] The direct compensation for asset loss and alternative livelihood is done by the dam construction companies following the national compensation rule. This private compensations are included in the cost-benefit analysis of the dam projects and borne by the dam companies.

derstanding of the governments' decision making process on dams and to distinguish the direct economic impacts and fiscal redistribution by local governments.

3 Theoretical Model

The following is a simple fiscal federalism model explaining governments' decision process for large infrastructures approved by the central government. The basic model setup is that there are two local governments (1,2) under the governance of the same central government. Each local government makes expenditures and provides public service to maximize social utility in the administrative region under a fiscal budget constraint independently, while the central government maximizes the weighted sum of utility in two localities. The main model structure follows the basic model setup on intergovernmental transfers proposed by Slack (1980) and Zou (2012). Local governments keep a vertical fiscal relationship with the central government, i.e. central government collects a certain share of tax revenues generated from the local governments and makes fiscal transfers down to local governments. The optimization problem is a typical Stackelberg game, with equilibrium solved by backward induction.

Assume that the decision on dam construction and dam impacts are exogenous for local governments. The central government has the final approval authority, while local governments have limited bargaining power about the location and approval of the dam projects *ex ante*. Once the project is approved, the impacts will be exogenous for local governments [15].

The fiscal relationship between central and local governments follows the fiscal federalism structure. The central government collects taxes from two localities to support its expenditure, and also makes intergovernmental transfers to localities for efficiency and equity considerations. Localities share fiscal tax revenues with the central government following the ratio of ρ: $(1-\rho)$, with local governments sharing ρ percent of total tax and central government sharing the rest[16]. The intergovernmental transfers from central government to local governments are reframed as the net transfer amount into local governments, because empirically there are transfers in both directions between local and central governments. The intergovernmental transfers are simplified to only one block transfer [17], which means the transfer amount is independent of local expenditure behavior

[15] Empirically, the decision on location and design of large-scale dam projects are mostly proposed by the river basin committee and Ministry of Water Resources under the help of research institutes affiliated to water resource department. Local county governments have little bargaining power on the location choices. But they *ex post* can raise project or program proposals and apply for the intergovernmental transfers from the central government.

[16] The tax sharing proportion is the same across the country. But different ratios may be applied for different taxes. For instance, valued-added tax is shared at 75:25 by the central and local governments. Income tax is shared at the ratio of 60:40.

[17] In reality, there are two types of intergovernmental transfers: block transfer and matching transfer.

[18].

3.1 Assumptions

The main assumptions for the model are the following.
1. There is no borrowing or saving for local governments across time periods. This is a static model for a one-shot game.
2. Government's utility function meets Inana conditions, i.e. (1) $U(0) = 0$; (2) $U' > 0$ and $U'' < 0$; (3) $\lim_{x \to +\infty} U(x) = 0$, $\lim_{x \to 0} U(x) = +\infty$.
3. There are no horizontal transfers directly among local governments.
4. The decision of dam construction and economic impacts of dam projects are exogenous to local governments.

Applying backward induction, the Subgame Nash Equilibrium (SGNE) can be solved by solving local optimization problem first and central optimization problem second as the following.

3.2 Local Government Optimization

Assuming two local governments make decisions simultaneously, i.e. one cannot observe another's action *ex ante*. Each government maximizes the utility of the presentative agent, subject to a budget constraint in the administrative region.

$$\begin{aligned} \max_{g_i} \quad & U_i(g_i)(i = 1, 2) \\ \text{s.t.} \quad & g_i \leq \rho t Y_i + f_i \end{aligned}$$

where U_i is the utility function of the representative individual as a function of public service provided by local government (g_i). The public service is assumed to be rival but non-exclusive. So g_i here is the per capita public service provided by the local government. t is the average tax rate. $\rho t Y_i$ represents the total tax revenue generated by the locality, as ρ being share held by the local government and t as the average tax rate. $(1 - \rho)tY_i$ is tax revenue collected by central government that is from locality i. f_i is the block transfer which is independent to local expenditure amount g_i. The expenditure or public service provided by local government is constrained by the total fiscal revenue, which is the sum of local tax revenue and transfer from the central government.

The utility is framed to be depending on public expenditure, because local governors can signal economic performance to upper-level governments for promotion or evalua-

Block transfer is the transfer independent of the local expenditure size and fields, while the matching transfer is the transfer correlated with local expenditures.

[18] If the transfers are specified as block and matching transfers. The main analysis results do not change much, because the matching factor for central governmental transfers are normally constant across regions.

tion(Li and Zhou, 2005). Tax rate is assumed to be constant here, because the whole country adopts the same tax rate structure except special development zones or poor regions with preferential tax rates. Most types of taxes apply an uniform tax rate, with exceptions for progressive tax rates applied on income taxes.

Solving the above problem using Lagrangian approach, the optimal local investment of locality i and j are:

$$g_i^* = \rho t Y_i + f_i \tag{1}$$

This is the static optimal result, meaning that local governments will spend out the available fiscal resource to maximize the public service provision utility. If a dam project brings local revenue impacts (ΔY_i) and external redistribution impacts (Δf_i), the change of local expenditure will be $\Delta g_i = \rho t \Delta Y_i + \Delta f_i$.

3.3 Central Government Optimization

Once predicting the optimal decision of local governments, the central government maximizes the weighted sum of utilities from two local governments, subject to the fiscal budget constraint.

$$\begin{aligned} \max_{f_1, f_2} \quad & \alpha U_1(g_1^*) + (1-\alpha) U_2(g_2^*) \\ \text{s.t.} \quad & f_1 + f_2 \leq (1-\rho) t (Y_1 + Y_2) \end{aligned}$$

Here α represents the constant weight that central government puts on locality 1, and $1-\alpha$ is the weight on locality 2. In addition, the central government is restricted by the budget constraint that total transfer should be no more than the tax revenue available to the central government, which is $(1-\rho)$ share of total tax revenue. So $(1-\rho)t(Y_1+Y_2)$ is the tax revenue shared by the central government.

Substituting g_1^* and g_2^* using the local optimization solution of equation (1), the central government's optimization problem can be solved using Lagrangian approach.

$$L = \alpha U_1(g_1^*) + (1-\alpha) U_2(g_2^*) + \lambda[(1-\rho)t(Y_1+Y_2) - f_1 - f_2]$$

FOC:

$$\begin{aligned} \frac{\partial L}{\partial f_1} &= \alpha U_g' g_1^{*\prime} - \lambda = 0 \\ \frac{\partial L}{\partial f_2} &= (1-\alpha) U_g' g_2^{*\prime} - \lambda = 0 \\ \frac{\partial L}{\partial \lambda} &= (1-\rho) t (Y_1 + Y_2) - f_1 - f_2 = 0 \end{aligned}$$

If the utility function is assumed as $U(g) = ln(g)$, the optimal transfer amount can be solved as the following.

$$\begin{aligned} f_1^* &= \alpha t (Y_1 + Y_2) - \rho t Y_1 \\ f_2^* &= (1-\alpha) t (Y_1 + Y_2) - \rho t Y_2 \end{aligned} \tag{2}$$

The optimal governmental expenditure or governmental service to be provided will be solved.

$$\begin{aligned} g_1^* &= \alpha t(Y_1 + Y_2) \\ g_2^* &= (1-\alpha)t(Y_1 + Y_2) \end{aligned}$$

The result indicates that the optimal governmental public service is a share of the total tax revenues from all localities. The share depends on the decision weight central government putting on local regions. Assume that a dam project brings net benefit ΔY to the country, the model implies that both governments will a proportion of the benefits from the project. However, the benefit proportions will be different for local governments depending on the decision weight and total population.

3.4 Propositions

Based on the above optimization results, we can derive three propositions related to the governmental fiscal transfer decision.

Proposition 1: *If local revenue decreases because of the infrastructure project, the transfer will increase. If local revenue increases, the change in transfer is uncertain.*

$$\Delta f_i^* | (Y_i < 0) > 0$$

This proposition can be derived from Equation(2) of the optimal transfer results. This proposition indicates that transfers can mitigate the negative revenue impacts.

Proposition 2: *The change in governmental economic performance or public good provision is equivalent to the sum of changes of local tax revenue and total received transfers.*

$$\Delta g_i^* = \rho t \Delta Y_i + \Delta f_i^*$$

Proposition 3: *The change in governmental fiscal resources is equivalent to the decision weight α.*

$$\Delta g_i^* = \alpha t(Y_1 + Y_2)$$

This proposition means that governmental economic performance can reveal information on the relative decision weight of local governments. There have been a lot of researches studying why the central government weigh local regions differently. The potential impacting factors include population of local region, iinequality aversion of the central government(Behrman and Craig, 1987), economic strength of local regions(Huang and Chen 2012 and Shih et al.), electoral productivity and partisanship(Castells and Sole-Olle, 2005), other political influence factors such as seats in the Political Bureau (Huang and Chen, 2012), media (Besley and Burgess, 2002) and ethnical composition. However, this paper only reveal the relative decision weights across different locations. The specific mechanisms why a certain region has higher or lower weights will not be verified.

3.5 Graphic Interpretation

To interpret the results graphically, the change in local tax revenue and change in intergovernmental transfer of one region can be plotted on a Cartesian Plane as shown in Figure(12). If we draw diagonal line passing original point O, it represents the original economic condition without infrastructure projects. Local revenue impacts of dam projects will push the outcome point away from the original point along the horizontal axis. The fiscal redistributive impacts from intergovernmental transfers will push the point away from the horizontal axis. The sum of horizontal and vertical values represents the change in governmental performance (Δg) under the internal and external revenue impacts from an infrastructure. The grey area below the diagonal line represents the worse-off outcomes, meaning that governmental performance is worse than the outcome without dam projects. Area above the diagonal line is the better-off zone for local governments.

If the dam project brings outcomes A and B as shown in Figure (12), it indicates that the project decreases the governmental revenue of A and increases the transfer to A, while increasing the governmental revenue of B and decreases the transfer to B. Combining the revenue and redistribution results together, the project is Pareto improving since both A and B are above the diagonal line. Proposition 3 from the theoretical model indicated that the relative location of A and B from the diagonal line may imply the decision weight of each local government, i.e α. The intercept of 45 degree line passing the point represents the governmental performance of that local government. We can call these 45 degree lines iso-wellbeing lines, because any point moving along the line generates the same governmental utility. The further the iso-wellbeing line is away from the diagonal line, the better-off the local government will be, and the higher the decision weight will be for that government.

In the following section, I use empirical data to estimate revenue and redistribution impacts of large dam projects on local governments in China. The estimates will be plotted on the Cartesian Plane to determine whether the dam projects are governmental Pareto improving or not.

4 Data and Summary Statistics

4.1 Dam and Hydrological data

Dam data was obtained from China Large Dam Management Committee(China ICOLD), covering all dams above 100 meters finished or under construction by 2003. I manually updated the dataset with newer dams based on China ICOLD report in 2008 and annual hydropower reports after 2008(CHINCOLD, 2008). In all, there are 143 dams above 100 meters by 2010. The dataset includes dam characteristics such as the official construction begin and finish year, dam location, reservoir volume, reservoir storage level, hydropower capacity, dam designed purposes and dam height. Dams were manually georeferenced based on the crosscheck of registered administrative location and Google Earth image location. The following analysis focuses on 136 Dams in mainland China[19].

The river stream network and basin information are from USGS Hydro1K dataset, which records detailed information on river streams, including stream length, river gradient, distance to the water head and distance to the water end. Each stream within the dataset is coded by a 6-digit Pfafstetter number, from which the related upstream and downstream streams can be identified[20]. Due to the limitation of Pfafstetter basin coding that it can only divide a basin into 9 sub basins in maximum, Pfafstetter basins might be inconsistent with empirically reported river basins. So I matched the Pfafstetter basin with real basin division to define the boundaries of basins. There are 25 major basins in China. A lot of the dams are located in Yangtze and Yellow river basins.

4.2 Economic data

The economic and demographic data were reported by National Bureau of Statistics in the Annual County Statistics Yearbook. The annual reports cover 2086 counties from 1996 to 2010, with information in economic, social and demographic perspectives. Main variables include GDP, population, consumption price index, total governmental revenue and total governmental expenditure. Population here refers to the reported population registered in the local county based on the Hukou system in China. So the population changes mainly capture the changes of involuntary migrations, job-related migrations involving Hukou change, births and deaths in the local region. Typical migrant workers, as rural labor force working in the urban areas, will not be included in the population change, because most of migrant workers still keep their original household registration.

Besides the above economic data, I also use local fiscal information, which were reported by Ministry of Finance annually on *China County-Level Fiscal Statistic Report*. Fiscal data are available from 1994 to 2006. It covers detailed categories of governmental fiscal activities, including local fiscal revenue, fiscal expenditure, and intergovernmental transfer from central government to local government, and transfer from local government to central government. I use net intergovernmental transfer, i.e. the transfer from central

[19] The rest 7 dams are in Taiwan.

[20] Each region was codes from large numbers to small numbers following the river flow direction, with odd number representing the interbasin or stem river, and even number representing the sub-stream river. The specific method to trace the upstream and downstream regions can be found at Furnans & Olivera (2001).

to local government minus the transfer from local to central government to represent the net transfer flow from central government to local governments.

Annual economic and fiscal data are adjusted according to the price level in 2000 based on annual consumption price index, to account for the price changes. On average, the population of a county is around 400,000. Mean GDP per person was around 12,000 CNY (around 1,700 US dollars) in 2006 using the 2000 price level. Governmental revenue per person was around 630 CNY and net intergovernmental transfer per person was around 930 CNY in 2006.

4.3 Agricultural data

To explore dam impacts on agriculture production, I use the agricultural production data provided by International Food Policy and Research Institute (IFPRI), covering agricultural yields and cropping areas of three crops (rice, wheat and maize) at county level in China from 1980 to 2000. Yields have increased significantly in the past several decades. The average yield for rice is around 6 tons per hectare. I drop yield and area outliers with value beyond three standard deviation from the annual average value for each county.

4.4 Weather Data

Because the operation and function of dams are closely linked to the weather condition in the basin or local region, I also collect temperature and precipitation data from 1980 to 2010. I calculated annual average temperature and precipitation in county level from monthly temperature recording in 0.5*0.5 grid level and monthly precipitation observations in 2.5*2.5 grid level (IRI/LDEO). The drought index was built based on the deviation of the annual precipitation record from historical precipitation level. The weather is defined as drought if the annual precipitation in a region is less than -0.7 standard deviation away from the historical average precipitation record.

5 Empirical Analysis

I use difference-in-difference approach to estimate the dam impacts, by comparing control and treatment counties before and after the dam construction. Ordinary least square (OLS) estimates will be biased because dam location may be impacted by local economic performance. The central government may distribute dam projects to a rich or poor region for promoting economic development and reducing inequality among regions. Many researchers used the instrument variable (IV) approach to estimate the causal effect of dam projects on different outcome variables, with river gradient as an instrument for geographic variations of dam locations (Duflo and Pande 2007, Strobl and Strobl 2011, Chakravarty 2011, Hansen et al. 2009, Lipscomb et al. 2011). A possible concern about the IV approach is exclusion restriction violation. River gradient can impact economic performance through other ways besides dam locations. For example, empirical data indicated that river gradient may impact highway and railway construction, since river gradient might be correlated with land steepness. Table(12) indicated that both railway and highway constructions are most frequent for environments with medium gradient, which is similar for dam projects(Duflo and Pande 2007).

5.1 Difference-in-Difference Approach

I define the control and treatment county groups based on the geographic variations of dam impacts from variations on distance to river and distance to the dam. Control and treatment counties are separately defined in upstream, dam-site and downstream regions. Most of the positive and negative impacts from dam projects rely on the natural water flow directly, such as flood control, irrigational water supply, power generation, navigation and tourism, dam-induced migration and water use restrictions. So regions closer to the river are exposed to more impacts comparing to regions further away.

Treatment counties are defined as counties with geographic centroids located within the 20km neighborhood [21]near the dammed-river. Control counties are defined as counties located next to the treated counties but further away from the river. So the control and treat counties have similar geographic topography such as slope and elevation, weather, ethnical composition, provincial governance, except the only difference in distances to river. Control counties are defined slightly differently in upstream and downstream regions. Because downstream counties are normally flatter and smaller in size than upstream counties in China, upstream control counties are defined in a broader scale than downstream control counties. Upstream and dam-site control counties are counties with centroids located more than 20km but within 100km neighborhood of the river. Downstream control counties are these with centroids located between 20 and 50km away from the river. In addition, based on the inundation and dam construction records of each dam, counties directly involved in the land inundation and displacement records were marked as treatment counties. In this way, each dam has its corresponding upstream control, dam-site control, downstream control and treatment groups.

Besides defining the comparable control and treatment counties, the temporal periods area divided into three categories, before dam construction, during dam construction and

[21]The average width/length of the county polygons is around 40km. This means that counties with river pass through will most likely be included in the treatment group. Counties close enough to the river, even with the river not directly passing through, will be also included in the treatment group, because they bear impacts from the dams, like water supply by canal network, and dam-related construction activities.

after dam being constructed. "Before" periods are defined as two years before the official dam construction begin year, because there are preparatory construction[22] and anticipatory economic activities before the official dam construction year. "During" periods are defined as one year before construction and years with actual construction work. "After" periods are defined as years after the official dam construction finish year.

The dam treatment is defined as the dam impacts from the nearest large-scale dam project. Since a county can be subject to the impacts of multiple dams, here I assume the nearest dam matters most for the economic condition of a region. Each treatment county is linked to the nearest dam based on distance between the county and dams along the river. The control counties can be used as multiple controls for different dams. The validity of nearest dam assumption here will be verified using the second closest dam as a sensitivity test in the following analysis.

The main assumption for DID estimation is that control and treatment counties should follow the same trend before dam construction, so that the growth in control and treatment counties would be the same if dams were never built. Table(3) plots the trend difference of treatment and control counties in upstream, dam-site and downstream regions. It indicates that treatment and control counties in three regions follow similar trends for most variables before dam construction periods. The smaller pre-trend of dam-site treatment counties on net transfers and the larger pre-trend of upstream treatment counties on precipitation may imply that the DID estimates might be downward biased. The larger pre-trend of upstream treatment counties on transfer is not robust on weather control.

In addition to the homogenous pretrend assumption, there are concerns about the uncertainty of DID estimators from panel data with long time series. Because the treatment status changes very little in the long time series and the dependent variable will be highly serial correlated, the standard error of estimates will be underestimated using typical DID approaches. A potential solution to the problem is to ignore the time series information and collapse data into two periods, before and after the treatment. The regression estimates based on the collapsed data will be unbiased (Bertrand et al. 2004, Donald and Lang 2007). In the result reporting part, I report both the simple DID estimates and DID estimates using collapsed data.

5.2 Empirical Approach

In the following section, I use two specifications to estimate the average impacts of dam projects and the temporal heterogeneity of dam impacts for each location group separately.

[22] Regulations in China requires that large-scale infrastructures should finish "San Tong Yi Ping" (access to water, electricity, road and land leveling) before the official construction.

The regression specification for estimating average impacts of dam impacts is:

$$\begin{aligned} y_{idpt} &= \beta_0 + \beta_1(\mathrm{Up}_i * \mathrm{T}_{id} * \mathrm{P1}_{idt}) + \beta_2(\mathrm{Up}_i * \mathrm{T}_{id} * \mathrm{P2}_{idt}) + \beta_3(\mathrm{Vicinity}_i * \mathrm{T}_{id} * \mathrm{P1}_{idt}) \\ &+ \beta_4(\mathrm{Vicinity}_i * \mathrm{T}_{id} * \mathrm{P2}_{idt}) + \beta_5(\mathrm{T}_{id} * \mathrm{P1}_{idt}) + \beta_6(\mathrm{T}_{id} * \mathrm{P2}_{idt}) + \gamma M_{idt} + \delta X_{it} \\ &+ \rho_t + \lambda_i + \zeta_p t + \epsilon_{idt} \end{aligned} \tag{3}$$

where T_{id} is a dummy variable indicating whether i is a treatment or control county for dam d. $\mathrm{P1}_{idt}$ and $\mathrm{P2}_{idt}$ are dummy variables showing whether county i in year t is in the dam construction or operation periods of dam d. Up_i and $\mathrm{Vicinity}_i$ are dummy variables indicating whether i is in the upstream or dam-site region of dam d, the default group is set as "downstream". M_{idt} are the interactions between location and treatment status, and interactions between location and dam periods. $\hat{\beta}_5$ and $\hat{\beta}_6$ are the estimates for average treatment effect(ATE) for downstream counties. $\hat{\beta}_1 + \hat{\beta}_5$ and $\hat{\beta}_2 + \hat{\beta}_6$ are the ATE estimates for upstream counties. $\hat{\beta}_3 + \hat{\beta}_5$ and $\hat{\beta}_4 + \hat{\beta}_6$ are the ATE estimates for dam-site counties. The above specification provides similar results as DID estimates for each location separately.

X_{it} are temperature and precipitation controls for i in province p in year t. The regression includes county fixed effect (λ_i), year fixed effect (ρ_t) and provincial trend ($\zeta_p t$) to capture the impacts of geographic endowment, annual variation and different provincial growth trends on outcome variables. Errors are clustered at dam level to correct correlations among counties linked to the same dam in the same basin, considering that dam operation impacts counties in the basin coherently and the dam construction decision involves basin level integrated planning.

Besides the static estimates of dam effects in the dam construction and operation period, I also estimate the temporal variation of dam effects at different years, using the following specification at upstream, dam-site and downstream regions separately.

$$y_{idpt} = \sum_{t=-8...16} \beta_t \mathrm{treat}_i * \mathrm{Dyear}_{it} + \delta X_{it} + \rho_t + \lambda_i + \zeta_p t + \epsilon_{idt} \tag{4}$$

where Dyear is the normalized year relevant to the official dam construction year. The regression included 25 years, ranging from 8 years before dam construction to 16 years after the official dam construction year. The default group is set at 2 years before the official dam construction year. The regression includes year fixed effect, county fixed effects and provincial trend. The errors are clustered at dam level.

6 Results

The following section reports the estimates of average dam impacts on governmental revenue, net transfer, economic and agricultural outcomes in upstream, dam-site and downstream regions. The spatial and temporal heterogeneity are also explored. One thing to be noticed is that here I only estimating the impacts of large-scale dams on upstream, dam-site and downstream administrative regions, instead of the actual geographic upstream and downstream regions, considering that a local administrative region may spread across the geographic upstream and downstream areas simultaneously.

6.1 Governmental Revenue

Table(4) provides the DID estimates for local governmental revenue impacts of large-scale dams from Equation (3), with logarithm of per capita governmental revenue as the dependent variable. The first column reports governmental revenue impact estimates using all county samples. The "treat*during" coefficient captures dam construction impacts, and the "treat*after" coefficient captures dam operation impacts. The estimate for upstream construction effect is the linear combination of $\beta_1 + \beta_5$. Similarly. the estimates for upstream operation and dam-site regions are also linear combination results. Column (1) indicates that upstream counties suffer a 16.5% decrease in governmental revenue during operation periods and an 7.5% decrease insignificantly during dam construction periods. Dam-site counties benefit in both dam construction and dam operation periods. But the magnitude of dam operation benefit is much larger than that of dam construction benefit, with revenue increasing by almost 20% in the operation periods. This is consistent with the previous evidence that local counties benefit from increased economic activities in the dam construction periods and increased tax revenue from electricity sell from hydropower generation. Nevertheless, downstream counties show insignificant and negative coefficients in both periods, implying slight economic worse-off results. There are worries that the results might be driven by specific county group, specific dams and provinces. The rest of the table reports various of sensitivity checks. Column (2) reports the results using counties located within 1000km away from the day. Coefficients are almost the same as the full sample results. Column (3) reports the results by dropping top invested dams with investment larger than 20 Billion CNY. It shows that the uneven revenue impacts are not dominated by heavily invested large-scale infrastructure projects. Due to the geographic conditions for dam projects, dams tend to be concentrated in several provinces, such as Sichuan, Hubei and Guizhou. To verify that the estimates are not driven by the changes of governmental revenue in these provinces, Column (4) reports the results by dropping the top 4 provinces with most counties connected to dams. Column (5) is an additional sensitivity check on the estimates by dropping weather controls. It indicates that the main results remain robust. To correct the serial correlation concerns caused by a few treatment status in the long times series, Column (6) reports the results using Duflo and Pande (2007) data collapsing approach, to collapse all periods into three time points (before, during and after) for each county. It shows that the revenue impact estimates for dam-site regions remain robust, while the upstream revenue effects are not significant.

Dam impacts on local governmental revenue show great geographic heterogeneities. Figure(5) shows estimates in different distance bins in upstream, dam-site and downstream regions. The closer a county is to a dam, the larger the impacts are. Most of the negative revenue impacts occur in upstream counties located within 200km away from the dam, which is the same for both dam construction and dam operation, with revenue decreased by more than 20%. This region is also the area exposed to direct inundation, migration, social structure disruption and water quality regulations.

In addition to the different impacts from dam construction and dam operation, temporal heterogeneity of dam impacts are analyzed following regression Equation(4). Considering that counties within 200km away from the nearest dams are exposed to the largest impacts, Figure(6) plots out the annual estimates for dam impacts on governmental revenue in upstream, dam-site. downstream and all three regions, with upstream and downstream counties located within 200km away from the nearest dam. Because there are quite few treatment status changes in a given year, there might be serial correlation concerns for the annual estimates. The negative impacts of upstream region are not quite significant. For the dam-site regions, the positive impacts on governmental revenue begin from the 1 year before the official dam begin year and becoming larger gradually. The largest revenue effect is observed 7-8 years after the dam construction, which is also the beginning period of full dam operation, considering that a dam takes 6-7 years to be built on average. If the analysis is done in all three regions, there are no significant dam impacts on the governmental revenue. but the direction of the estimates are positive.

Both the geographic and temporal heterogeneities of dam impacts imply that dam operation causes much larger uneven impacts than dam construction in both upstream and dam-site regions. This is different from the usual arguments about negative dam impacts in the construction periods on upstream regions. There are several potential reasons. One is that actual inundation only begins a few years before the full operation time, even though population migration may occur in the whole construction periods. Dam construction itself doesn't change the hydrological cycle to upstream regions much, because the river will be diverted to an alternative path. The revenue base in upstream will not be impacted much during most of the construction periods. Another reason might be that dam construction has a lag effect on the governmental revenue, considering that the economic, social and environment disruption may take time to be reflected into economic performances. Even though the migrants are compensated directly for the damages they suffer, the social impacts or other indirect social costs are not compensated.

6.2 Intergovernmental Transfer

The second set of results is on the external revenue source of local governments, net intergovernmental transfers. Table (5) reports the estimates for changes in per capita net transfer due to dam projects. The general structure is the same as that for governmental revenue. Column (1) reports the estimates using the whole sample. Column (2)-(5) report the estimates using nearby county samples, non-heavily-invested dams, provinces less concentrated with dams, and regression without weather controls. Upstream and dam-site regions receive higher transfers from dam projects. The net transfer into upstream counties increases by 13.6% from construction and less from dam operation. Dam construction and operation increases net transfer into dam-site counties by more than 16.6%. For both the upstream and dam-site transfer effects, dam construction brings a larger transfer effect than operation. This is different from the temporal pattern of local governmental revenue impact, which is larger in dam operation periods. The net transfer to downstream regions shows insignificant deceases in both the operation and construction periods. The results are robust for counties located within 1000km away from the nearest dam, dams with less fixed investment and provinces less concentrated with dams. So dams with large investment bring almost the same transfer increase to dam-site counties, implying that transfers are not fully for dam investments. The transfer increases are not restricted to dam-concentrated provinces.

The transfer impacts also show geographic heterogeneities, as plotted in Figure(7). Upstream counties located closer to the dam have an increase in net transfers, especially counties located within 200km away from the nearest dam. For counties located further away in the upstream, the positive transfer effects are smaller. Transfers into downstream counties within 200km away from the day decrease slightly, even though the decrease is not statistically significant. Figure(8) plots the temporal heterogeneities of transfer impacts for upstream and downstream counties located within 200km away from the dam, since counties in this distance are subject to larger impacts on transfers. The top-left graph of temporal heterogeneities of dam impacts in the upstream shows similar pattern as the construction and operation estimations. Transfers increase significantly from the official construction year and 6 years after the official construction year. Then the transfer increases become much smaller after 7 years. The top-right graph in Figure(8) shows that the transfer into dam-site counties increase slightly but not statistically significant, potentially due to linear correlation among year dummies or the lower pre-trend in treatment counties before the dam construction period. Table(3) shows that treatment counties in the dam-site region have a smaller growth rate than dam-site control counties. However, the above estimates result reveal that dam bring a positive transfer effect to dam-site regions. So the negative pre-trend difference in the dam-site region works favoring my estimation. Net transfer in downstream regions are not significantly impacted.

The geographic heterogeneity of dam impacts in different distance bins on governmental revenue and intergovernmental transfer implies that governmental transfers change in the opposite direction of governmental revenues in upstream and downstream regions, verifying the first proposition in the theoretical model. Even though there is no explicit regulations or policies regulating that the net transfers are used to compensate the governmental revenues in the upstream regions, the opposite movement of external net governmental transfer and internal governmental revenues indicates that intergovernmental transfers redistribute some of the uneven impacts of large-scale dams in different regions and balance the revenue sources of local county governments. However, the temporal pattern of transfer impacts in two dam periods are not coherent to the temporal pattern of revenue impacts. Dam construction brings larger transfer effects and smaller revenue effects than dam operation.

6.3 Economic Production GDP

Table (6) lists the regression results for dam impacts on logarithm of per capita GDP. It indicates that dam projects reduce per capita GDP in the upstream counties with a small decrease during the dam construction period and 6.5% decrease in dam operation period. Downstream regions also experience small decreases in logarithm of per capita GDP. Dam-site regions experience increase in per capita GDP, by around 3% in both dam construction and operation periods. If the county samples are restricted to upstream and downstream counties located within 1000 km away from the nearest dam, as shown in column (2), the negative impacts of downstream regions are not statistically significant any more while the operation negative impacts on upstream counties remain significant at 90% confidence level. Column (3) and column(4) show that the different GDP impacts in upstream, dam-site and downstream regions are not dominated by dams with large investment costs and provinces concentrated with dams. The consistent negative impacts from dam operation reinsure that there might be lagging social impacts caused by the migration and other social costs due to water use restriction to the upstream regions besides the immediate economic impacts from dam-driven migration. Using data collapsing approach to deal with the serial correlation concerns of county GDP, column (6) shows that the estimates for dam-site regions remain robust, while the estimates for upstream regions switch direction, potentially because of the smaller observations in upstream regions reflecting from the larger magnitude of estimates and large standard errors.

The distributive impacts of dam projects on logarithm per capita GDP also shows geographic heterogeneities, as reported in Figure (11). Counties located within 200km upstream of the dam suffer from larger GDP losses in the operation period, while counties farther away in the upstream are barely impacted. The impacts of dam projects on downstream regions are more complex. Downstream counties closely nearby (within 200km away from the dam site)benefit from an increase in per capita GDP, while downstream counties farther away (more than 200km) suffer from a drop in per capita GDP. This pattern is consistent with Chakravarty (2011) findings for dam impacts on child mortality for downstream benefits for nearby regions and losses for far downstream counties. Potential reasons for the different impacts to downstream regions are that nearby downstream counties benefit from water supply and irrigation, while further downstream regions may suffer from reduced water because of the water storage in the upstream. Figure(10) plots the temporal heterogeneities of GDP impacts of upstream and downstream counties located within 200km away from the nearest dam. The top-left subplot shows similar patterns as Table (6). Dam construction brings much larger GDP loss than dam construction.

6.4 Pareto Efficiency Analysis

According to proposition 2 of the theoretical model, the sum of governmental revenue and intergovernmental transfers represent the overall governmental economic performance. Different from GDP and income as the macroeconomic performance variables, the combination of governmental revenue and transfers emphasizes the governmental performance and the separation of internal and external sources of total fiscal revenue. In the governor promotion social contexts of China, governmental performance can be a strong motivation for governors to make investment decisions and signal their performances. In the following section, I will compare the governmental performance and overall economic performances for Pareto efficiency analysis.

Figure (13) and Figure (14) plot the estimated changes of local governmental revenue and intergovernmental transfers caused by large-scale dams in upstream, dam-site and downstream regions. Because the above regression specification use logarithm values as the dependent variables, the estimates are interpreted as percentages changes. Multiplying the estimates with mean values of the control counties before dam construction, we can get the value changes of each outcome variables using control counties before dam construction as the benchmark value. Both figures also plot the 95% confidence interval of the value changes.

Figure (13) shows that upstream and dam-site counties benefit from dam construction in the perspective of governmental fiscal capacity, while dam construction barely impacts downstream counties. dam-site counties benefit from a 23 CNY increase in local revenue and 52 CNY increase in received transfers per person. Upstream counties suffer from revenue loss amounting around 10 CNY, but receive an increase of transfer amounting around 50 CNY. Figure (14) shows that dam-site counties consistently benefit from dam operation. Upstream and downstream counties are close to the diagonal line, with governmental performance similar to the no-dam performance. For upstream counties in the dam operation period, governmental revenue decrease by 22 CNY per person, while the transfer increase in a smaller magnitude than that of dam construction period, at around 25 CNY per person just compensating the revenue loss. So dam projects are generally Pareto improving for different regions. No region get statistically worse off in governmental economic performance. Considering that counties located within 200km away from the dam are subject to the largest impacts, the outcomes for these counties are plotted in Figure (15) and Figure (16). Both figures imply that nearby counties show similar pattern as that of the whole sample.

The macroeconomic variable GDP result shows similar patterns for dam-site benefits. But upstream and downstream regions suffer from decreases in GDP, even though the effects are not statistically significant, except dam operation for upstream counties. Since total GDP is composed by economic performance of private sector, governmental sector and international trade sector, the difference between overall economic performance and governmental performance results reveals that private sector in the upstream region get slightly worse-off from dam construction. The negative impacts on private sector are not redistributed well through market mechanisms.

Applying proposition 3 of the theoretical model, the Pareto efficiency analysis results indicate that the central government put a higher decision weight on dam-site counties in the utility function for public service provision in face of dam projects. Upstream and downstream regions are barely considered, with the decision weights of both regions close to zero, except upstream counties in the dam construction period. In the whole process of dam construction and dam operation, dam-site counties are highly weighed by the central government. While upstream counties are only weighted in a small magnitude in the dam construction period, potentially due to the attention on migration, inundation and social structure disruption. But the weight becomes much smaller in the dam operation period, even though the negative revenue and GDP impacts are much larger.

6.5 Demographic and Agricultural Yields

Involuntary migration and agricultural impacts of dam projects have been widely studied as potential mechanisms leading to economic losses and benefits. Table(7) reports the dam impacts on level value of population, logarithm of population, average yield and planting areas of rice.

Total population are not significantly impacted by large-scale dam projects, even though upstream counties show a decrease in total population level value. However, the estimates on logarithm population in upstream counties show opposite direction with that of level values, potentially caused by the fact that dams cause migrations to population in a specific area instead of a proportion of the total population of the county. This results is consistent with involuntary migration in upstream regions. For most counties, dam normally inundates part of the administrative county. The migration policy prioritize local migration to external migration. However, the impacts on per capita governmental revenue reported in the above tables imply that the total upstream revenue decreases considering that population also decreases. The losses might be due to damage to social structure and social capital in the region.

Even though irrigational dam projects was believed to increase the downstream agricultural production significantly in India and Africa (Duflo and Pande 2007, Strobl and Strobl 2011), the analysis on agricultural impacts of hydropower dams in China indicates that upstream counties benefit from an insignificant increase in rice yield, while downstream counties suffer from rice yield drop, with a 5.4% decrease in dam construction period and 7.6% in dam operation period. The main downstream regions suffering from rice yield drop are counties located more than 200km away from the dam site, which is consistent to the negative GDP impacts in these regions. Rice planting areas show similar patterns as rice yields. The decrease of rice yield and area in the downstream regions corresponds to the reduced GDP and revenue found previously in downstream regions. One potential reason is the reduced water flow because of water storage in the upstream areas.

6.6 Dam Functions

As mentioned in the background section, dams with different designed functions operate differently. Hydropower dams store water in dry season to fill the reservoir and release water prior the flooding season to save space for flooding water storage. However, irrigational dams need to release water in dry season to downstream region and other agricultural service regions to provide irrigational water. There have been studies found that irrigational dams reduce weather variability in downstream significantly (Hansen et al. 2009, Duflo and Pande 2007). In the following section, I separately analyze the revenue and transfer impacts of hydropower and irrigational dams.

Table (8) lists the estimates for governmental revenue and transfer separately from two types of dams. An dam is classified as a hydropower or irrigational dam as long as hydropower generation or irrigation is listed as one of the main functions. From the governmental revenue results in column 2 and 3, hydropower dams contribute to more revenue than irrigational dams in dam-site counties, but also bringing more revenue loss to upstream counties. Hydropower dams increase revenue in dam-site counties by 17.2% in the operation period, while irrigational dams almost bring no significant revenue contribution to local dam-site counties. The result verifies that the revenue benefits in dam-site counties are mainly from electricity generation. The differences on revenue impacts are not because of the size or height of dams, because there are no significant differences between the heights of two types of dams, considering that most dams includes both functions as the designed purposes. From intergovernmental transfer results in column 4 and 5, dam functions do not have big impacts on the transfers to local dam-site counties. But upstream counties receive more transfers from hydropower dams than irrigational dams.

6.7 Falsification Tests

To verify that the main results I obtained are not because of factors correlated with the way I define the treatment and control groups, or factors correlated with the way to link treat counties to the nearest dam, I run two falsification tests. The first falsification test is to test the validity of dam treatment. I randomly assign treatment status to counties following the proportion of treatment and control counties in the analysis, keeping the linkage of counties and dams as they are. The governmental revenue estimates from this falsification test is reported in column (2) in Panel A of Table (10). The estimates for upstream and dam-site counties in both the dam construction and dam operation periods are not significant. The magnitudes of the coefficients are also quite different from the original DID results as in column (1). The intergovernmental transfer outcome from this falsification is reported in column (2) in Panel B of Table (10). None of the estimates for upstream and local regions are significant. This convinces us that the original definition of treat and control groups is crucial for the estimate results.

The second falsification test is to test the temporal dependence of the estimate results. Here I randomly assign the dam construction year to each dam, maintaining the dam construction length and linkage between counties and dams. The dam construction begin year is assumed to follow a truncated normal distribution between 1980 and 2010, with the mean and standard deviation the same as the original begin year. So the dam construction period will still be the same length, but with different construction begin year and finish year. This falsification test can verify how strong the result relies on the correct identification of dam construction and dam operation period. The result was listed in column(3) of Table (10) for governmental revenue and intergovernmental transfers. The estimates for local and upstream counties are not significant any more for both the governmental revenues and net intergovernmental transfer. However, the pattern of stronger dam operation effects than dam construction effects is observed in this falsification test, because the dam construction and dam operation in the falsification test follow similar orders as the original.

The comparison between the original results and results from two falsification tests indicates that correctly specifying the treatment and control status and dam construction begin year is crucial to estimate the distributive and redistributive impacts of dam projects. The estimates on revenue and transfer impacts are not caused by other variations beyond the treatment status and different periods.

Because there are concerns about using the nearest dam only to estimate the dam impacts on counties, I checked the impacts of second-layer dams, i.e. the second closest dam to a county to see how excluding the second layer or farther dams impacts the dam estimates. The results are listed in Table (11). The second layer dams do not impact the net governmental transfer significantly in the upstream and downstream regions. However, the second closest dam still decreases governmental revenue in the dam operation periods to upstream regions significantly. This may imply that the actual economic impacts of counties from dam projects may be underestimated using only the nearest dam.

6.8 Discussion

The impact estimates are different from the results obtained by Duflo and Pande (2007) and Strobl and Strobl (2011), where they found positive agricultural benefits to downstream regions from irrigational dams in India and Africa. One potential reason is that the operation scheme of hydropower dams differs from that of irrigational dams, which was illustrated from the comparison of hydropower and irrigational dams in the previous section. For hydropower dams, the primary purpose is power generation, which requires storing water in the dry autumn season and releasing water for water generation. While for irrigational dams, the primary purpose is to provide irrigational water use to the downstream regions, which requires the dam to release water in the dry season. The water storage in dry season for hydropower dams may severe the drought condition in downstream regions, while the irrigation services of irrigational dams can relieve the drought condition in downstream regions. Another possible reason is that the outcome variables are different. I mainly analyze the impacts on governmental revenue and GDP, which include other non-agricultural impacts, such as construction work, tourism and other economic impacts beyond agriculture. Even though dam projects may decrease agricultural production due to water seepage or inundation, they also bring a lot of other economic activities, such as road construction, infrastructure improvement and increasing job opportunities.

7 Conclusions

Governments globally encourage infrastructure investment to promote economic development. However, a lot of the infrastructure projects may bring unevenly distributed impacts to different locations, with large-scale dams as one example. Dam projects have been controversial for the benefits on power generation, flood control and irrigation, and damages from environmental and social impacts of inundation and hydrological change.

The benefits and damages are distributed geographically unevenly among different regions, depending on the location along a river. Are the negative impact caused by dam projects mitigated by the market and governmental mechanisms? Are the dam projects Pareto improving? This paper answers these questions in China, since more than half of the large-scale dam projects are located in China. The central decision making process of dam projects in China also makes it meaningful to answer these questions for policy perspectives.

Using variations of dam impacts from the distances to the dam and distances to the river, this paper adopts DID approach to estimate the dam impacts on fiscal, economic and agricultural outcomes. The governmental economic performance is evaluated for Pareto efficiency analysis, by separating the external and internal revenue sources of local county governments. Overall, large-dam projects are Pareto improving in the perspective of governmental economic performance, with no region getting significantly worse off. dam-site dam-site counties capture most of the economic benefits. Revenue losses in the upstream counties are mitigated by intergovernmental transfers, even though the transfer amounts are different in dam construction and operation periods.

Dam projects increase per capita governmental revenue to dam-site dam-site counties, with an average 13% increase during dam construction period and 20% increase during dam operation period from a dam above 100 meters. Upstream counties suffer a 16.5% decrease in per capita governmental revenue during dam operation period, while downstream counties are not significantly impacted, potentially due to the confronting impacts from flood control benefits and reduced water flow. Generally, dam operation brings larger distributive impacts than dam construction. The external intergovernmental transfers mitigate the negative revenue impacts sufficiently. Upstream counties receive an increase in transfers, with a 13.6% increase during dam construction period and a 6.7% increase during dam operation period. dam-site dam-site counties also receive more transfers, with an increase by more than 16% in both periods. Transfers to the downstream regions were not significantly observed. Unlike the large tax revenue impacts in dam operation periods, the redistributive transfers show a larger response to dam projects in dam construction period. The above results are not driven by top invested dams and big provinces. The main results are robust even when correcting the serial correlation concerns caused by too few treatment status in DID analysis with long time series.

Dam impact estimates show geographic and temporal heterogeneities, depending on the distance of a county to the dam. Counties which are located within 200km away from the dam-site are impacts more significantly than these further away. This confirms that the economic impacts on economic and fiscal performances in counties are associated with dam functions of power generation and reservoir storage. For other outcome variables beyonds governmental economic indicators, the estimates on logarithm population are not significant, potentially because the migration policy in China prioritize local resettlement.

Rice yields in downstream regions are negatively impacted, potentially due to reduced water flow. Counies further downstream suffer a larger rice yield loss. These results are not consistent with the downstream agricultural benefits from irrigational dams observed by Duflo and Pande (2007) and Strobl and Strobl (2011). The reason may be due to the different design functions of dams. Hydropower dams tend to generate a larger uneven impacts across different regions, because of their special operation scheme to store water in the dry season.

By combining the fiscal distributive and redistributive impacts of dam projects, this paper provides an empirical approach to analyze the Pareto efficiency in the perspective of governmental economic performances in China. Even though estimates for GDP per capita also shows similar directions as the combination results of revenue and redistributive transfer outcomes, the separation of internal and external revenue sources provide a clearer view of the governmental redistributive mechanism in face of uneven impacts. It can shed some light on the policy implications on hydropower dam investment and intergovernmental redistribution decision making in China.

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Tables and Figures

Table 1: Dam construction history in China

	($\geq$100m)		Large Dams($\geq$30m)	
Year	N	new dams per year	N	new dams per year
1973	21		1644	
1988	42	1.31	3768	132.75
2005	129	4.83	4839	59.5
2008	142	3.25	5191	88

Table 2: Descriptive Statistics of Upstream Areas in the Pre-dam Construction Period

			Up			Dam-site			Down	
Variable	Unit	Control	Treat	Diff	Control	Treat	Diff	Control	Treat	Diff
pop	1000	43.7	33.8	-10.0***	42.7	38.7	-4.03	53.9	55.7	1.8
GDP	Yuan/person	2909	3645	736*	3655	3566	-89.12	4312	5135	823***
GDP growth rate	%	0.1	0.1	-0.02+	0.1	0.1	-0.004	0.1	0.1	-0.006
yield(rice)	t/ha	5.2	5.1	-0.07	5.2	5.2	-0.03	5.6	5.7	0.078+
yield(wheat)	t/ha	2.1	2.2	0.05	2.0	2.1	0.10*	2.3	2.6	0.29***
yield(maize)	t/ha	3.3	3.2	-0.04	3.1	3.2	0.001	3.3	3.4	0.10*
rice area ratio	%	0.4	0.3	-0.006	0.4	0.4	-0.025+	0.5	0.5	-0.02**
temp	C degree	11.0	8.7	-2.31***	13.4	12.4	-1.03***	13.8	13.2	-0.57***
precip	mm/day	2.5	2.5	-0.06*	3.1	3.0	-0.14***	3.3	3.0	-0.23***
pc tax revenue	Yuan/person	131	201	70**	181	173	-8.04	163	189	26***
pc gov expenditure	Yuan/person	691	786	95	575	491	-84.31*	335	381	46*
pc transfer	Yuan/person	368	524	156***	281	249	-32	202	176	-26
lnpcgdp		7.8	7.9	0.09*	8.0	8.0	0.01	8.2	8.3	0.1***
lnpop		3.3	2.6	-0.71***	3.5	3.4	-0.09	3.7	3.8	0.05
lnpcgov revenue		4.7	4.8	0.17**	4.8	4.9	0.11	4.9	5.0	0.11**
lnpc transfer		5.3	5.7	0.4***	5.3	5.2	-0.1	4.8	4.7	-0.069
slope	0.01 Degree	362	424	62*	482	547	65	252	230	-23
dem	m	1479	1873	393.8**	1294	1420	125	535	507	-28
river flow		604	2693	2089**	1579	2763	1185	1124	7229	6104***

Notes: Diff is the difference between outcomes in the treatment and control counties. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Homogenous trend test before dam construction

	Upstream	Dam-site	Downstream
pop	-0.01	0.11	-0.19
GDP	-31.92	21.03	8.17
GDP growth rate	0.011	-0.001	0.004
yield(rice)	0.001	-0.003	-0.005
yield(wheat)	-0.01	0.01	0.006
yield(maize)	-0.01	-0.02	-0.005
area(rice)	-28.57	-72.84+	49.07
area(wheat)	-20.58	-18.99	-95.05**
area(maize)	8.06	-35.27	-99.36
rice area ratio	-0.0003	0.00008	0.001+
temperature	-0.005	-0.002	0.003
precipitation	0.007*	0.002	0.00008
gov revenue	-4.76	3.13	2.88
gov expenditure	58.41	-5.19	-5.90
transfer	82.29+	-13.14*	-0.23

Notes: Economic variables of GDP, governmental revenue, governmental expenditure, transfer are in per capita terms. Coefficients are β estimates from $y_{ipt} = \beta \text{treat}_i * \text{year}_t + \alpha_p * \text{year}_t + \gamma_i + \rho_t + \epsilon_{ipt}$ for all upstream, dam-site and downstream regions separately two years before the official dam construction begin year. Standard errors were clustered at dam level. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 4: Impact of Dams on Governmental Revenue

Dependent Variable: Log per capita Governmental Revenue						
	(1) DID	(2) ≤1000km	(3) drop top invested dams	(4) drop top 4 provinces	(5)	(6) collapse
UP*treat*during	-0.075	0.006	-0.032	-0.164	-0.074	0.007
	(0.078)	(0.111)	(0.078)	(0.109)	(0.078)	(0.099)
UP*treat*after	-0.165+	-0.127	-0.093	-0.249*	-0.165+	0.039
	(0.089)	(0.122)	(0.093)	(0.118)	(0.089)	(0.133)
Dam-site*treat*during	0.129+	0.128+	0.137+	0.160*	0.129+	0.174*
	(0.074)	(0.075)	(0.078)	(0.077)	(0.075)	(0.084)
Dam-site*treat*after	0.199*	0.194*	0.218*	0.260*	0.199*	0.200+
	(0.084)	(0.085)	(0.087)	(0.098)	(0.084)	(0.111)
DOWN*treat*during	-0.044	-0.025	-0.047	-0.045	-0.044	-0.055
	(0.036)	(0.050)	(0.032)	(0.049)	(0.037)	(0.068)
DOWN*treat*after	-0.069	-0.031	-0.047	-0.129*	-0.070	-0.120
	(0.060)	(0.073)	(0.065)	(0.063)	(0.060)	(0.127)
N	13863	11526	10556	8912	13863	2245
Weather Controls	Y	Y	Y	Y	N	-
CFE	Y	Y	Y	Y	Y	Y
YFE	Y	Y	Y	Y	Y	-
Trend	province	province	province	province	province	-
Error Clustering	Dam	Dam	Dam	Dam	Dam	Dam

Notes: The coefficients of upstream and dam-site regions are the linear combination results from regressions with downstream set as the default group. Column (2) reports estimates for counties located within 1,000 km away from the dam.Column (3) reports the estimates dropping dams with investment larger than 20 Billion CNY. Column (4) reports estimates from collapsed data following BDM(2004) approach. Column (5) reports estimates dropping the top 4 provinces (Sichuan, Hubei, Guizhou, Shaanxi) with counties linked to dams. Column (6) reports the estimates without weather controls. Weather controls include annual average precipitation and temperature. All regressions include county fixed effects and year fixed effects. Standard errors clustered at dam level in parentheses. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 5: Impact of Dams on intergovernmental Transfer

	Dependent Variable: Log per capita Net Transfer					
	(1) DID	(2) ≤1000km	(3) drop top invested dams	(4) drop top 4 provinces	(5)	(6) collapse
UP*treat*during	0.136**	0.124*	0.126+	0.159*	0.125*	0.338
	(0.051)	(0.057)	(0.073)	(0.068)	(0.051)	(0.248)
UP*treat*after	0.067	0.095	-0.076	0.0002	0.058	0.373
	(0.093)	(0.098)	(0.072)	(0.080)	(0.094)	(0.244)
Dam-site*treat*during	0.185**	0.180**	0.199**	0.200***	0.183**	0.153
	(0.059)	(0.058)	(0.065)	(0.057)	(0.059)	(0.107)
Dam-site*treat*after	0.166+	0.165+	0.158	0.164+	0.167+	0.166
	(0.092)	(0.090)	(0.098)	(0.095)	(0.094)	(0.148)
DOWN*treat*during	0.007	-0.023	0.022	0.006	0.008	0.032
	(0.054)	(0.059)	(0.051)	(0.069)	(0.053)	(0.084)
DOWN*treat*after	0.007	-0.027	0.071	-0.037	0.010	0.211
	(0.072)	(0.080)	(0.069)	(0.073)	(0.071)	(0.177)
N	9688	8067	7468	6158	9688	1947
Weather Controls	Y	Y	Y	Y	N	-
CFE	Y	Y	Y	Y	Y	Y
YFE	Y	Y	Y	Y	Y	-
Province Trend	province	province	province	province	province	-
Error Clustering	Dam	Dam	Dam	Dam	Dam	Dam

Notes: The coefficients of upstream and dam-site regions are the linear combination results from regressions with downstream set as the default group. Column (2) reports estimates for counties located within 1000 km away from the dam.Column (3) reports the estimates dropping dams with investment larger than 20 Billion CNY. Column (4) reports estimates from collapsed data following BDM(2004) approach. Column (5) reports estimates dropping the top 4 provinces (Sichuan, Hubei, Guizhou, Shaanxi) with counties linked to dams. Column (6) reports the estimates without weather controls. Weather controls include annual average precipitation and temperature. All regressions include county fixed effects and year fixed effects. Standard errors clustered at dam level in parentheses. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 6: Impact of Dams on GDP

	Dependent Variable: Log per capita GDP					
	(1)	(2)	(3)	(4)	(5)	(6)
	DID	≤1000km	drop top invested dams	drop top 4 provinces		collapse
UP*treat*during	-0.035	-0.023	-0.032	-0.015	-0.039	0.192+
	(0.027)	(0.032)	(0.035)	(0.035)	(0.028)	(0.106)
UP*treat*after	-0.065*	-0.077+	-0.047	-0.042	-0.069*	0.226*
	(0.032)	(0.039)	(0.042)	(0.039)	(0.032)	(0.095)
Dam-site*treat*during	0.038	0.039	0.042	0.039	0.037	0.053
	(0.046)	(0.046)	(0.049)	(0.042)	(0.046)	(0.052)
Dam-site*treat*after	0.033	0.035	0.035	0.077	0.033	0.044
	(0.054)	(0.055)	(0.056)	(0.060)	(0.054)	(0.069)
DOWN*treat*during	-0.040+	-0.011	-0.042+	-0.030	-0.041+	-0.033
	(0.022)	(0.032)	(0.021)	(0.032)	(0.022)	(0.045)
DOWN*treat*after	-0.068**	-0.037	-0.066*	-0.051	-0.068**	0.033
	(0.025)	(0.034)	(0.028)	(0.033)	(0.025)	(0.069)
N	12319	10234	9380	7937	12319	2124
Weather Controls	Y	Y	Y	Y	N	-
CFE	Y	Y	Y	Y	Y	Y
YFE	Y	Y	Y	Y	Y	-
Province Trend	province	province	province	province	province	-
Error Clustering	Dam	Dam	Dam	Dam	Dam	Dam

Notes: The coefficients of upstream and dam-site regions are the linear combination results from regressions with downstream set as the default group. Column (2) reports estimates for counties located within 1000 km away from the dam.Column (3) reports the estimates dropping dams with investment larger than 20 Billion CNY. Column (4) reports estimates from collapsed data following BDM(2004) approach. Column (5) reports estimates dropping the top 4 provinces (Sichuan, Hubei, Guizhou, Shaanxi) with counties linked to dams. Column (6) reports the estimates without weather controls. Weather controls include annual average precipitation and temperature. All regressions include county fixed effects and year fixed effects. Standard errors clustered at dam level in parentheses. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 7: Impacts of Dams on Demographic and Agricultural Variables

	pop	lnpop	yield rice	area rice
		Dam Construction(during)		
Upstream	-1.173+	0.012	0.027	0.023
	(0.671)	(0.012)	(0.038)	(0.123)
Dam-site	2.370	0.028	-0.014	-0.051
	(2.684)	(0.028)	(0.034)	(0.070)
Downstream	0.026	-0.003	-0.054**	-0.136
	(0.540)	(0.011)	(0.020)	(0.097)
		Dam Operation(after)		
Upstream	-1.286	0.003	0.055	0.125
	(0.797)	(0.012)	(0.044)	(0.143)
Dam-site	2.144	0.022	-0.021	-0.048
	(2.689)	(0.028)	(0.038)	(0.093)
Downstream	-0.405	-0.008	-0.076***	-0.118
	(0.862)	(0.018)	(0.018)	(0.078)
N	13931	13931	13833	13539

Notes: Each column is a separate regression for the dependent variable. Upstream and dam-site coefficients are the linear combination from the regression with downstream set as the default location group. All regressions include precipitation and temperature controls, year fixed effects, county fixed effects and provincial trend. Standard errors clustered at dam level in parentheses. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 8: Impacts of Dams With Different Design Functions

	Gov. Revenue		Transfer	
	Hydropower	Irrigation	Hydropower	Irrigation
UP*treat*during	-0.132	0.024	0.129*	0.068
	(0.094)	(0.081)	(0.057)	(0.063)
UP*treat*after	-0.235*	-0.111	0.057	0.003
	(0.095)	(0.086)	(0.095)	(0.124)
Dam-site*treat*during	0.095	0.027	0.176**	0.193
	(0.076)	(0.132)	(0.060)	(0.115)
Dam-site*treat*after	0.173+	0.039	0.163+	0.163
	(0.087)	(0.159)	(0.093)	(0.161)
DOWN*treat*during	-0.020	-0.005	-0.031	0.015
	(0.039)	(0.057)	(0.056)	(0.054)
DOWN*treat*after	-0.038	0.002	-0.027	0.017
	(0.062)	(0.088)	(0.074)	(0.084)
N	12096	8229	8473	5673
Weather Controls	Y	Y	Y	Y
CFE	Y	Y	Y	Y
YFE	Y	Y	Y	Y
Province Trend	province	province	province	province
Error Clustering	Dam	Dam	Dam	Dam

Notes: Each column is a separate regression for the dependent variable using subsample counties which are linked to dams with one function or another. Hydropower dams are dams with hydropower generation listed as one of the functions. Irrigation dams are dams with irrigation listed as one of the functions. Upstream and dam-site coefficients are the linear combination from the regression with downstream set as the default location group. All regressions include precipitation and temperature controls, year fixed effects, county fixed effects and provincial trend. Standard errors clustered at dam level in parentheses. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 9: Impacts of Dams of River Flow

	(1) flow January	(2) flow August
UP*treat*during	7.889*	0.917
	(3.251)	(0.998)
UP*treat*after	10.684**	-12.463***
	(3.873)	(2.102)
Dam-site*treat*during	-14.886	0.382
	(12.826)	(2.445)
Dam-site*treat*after	-14.726	-2.054
	(12.310)	(2.882)
DOWN*treat*during	-0.345	-1.791
	(0.957)	(1.477)
DOWN*treat*after	-2.526	-5.608+
	(2.555)	(3.185)
N	2817	1689

Notes: Hydropower dams are dams with hydropower generation listed as one of the functions. Irrigation dams are dams with irrigation listed as one of the functions. Upstream and dam-site coefficients are the linear combination from the regression with downstream set as the default location group. All regressions include precipitation and temperature controls, year fixed effects, county fixed effects and provincial trend. Standard errors clustered at dam level in parentheses. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 10: Falsification Test of the DID results

	(1)	(2)	(3)
	original	randomize treatment county	randomize dam begin-year
Panel A: Log per capita Governmental Revenue			
UP*treat*during	-0.075	0.039	-0.107**
	(0.078)	(0.059)	(0.033)
UP*treat*after	-0.165+	-0.001	-0.180*
	(0.089)	(0.064)	(0.087)
Dam-site*treat*during	0.129+	-0.014	0.060
	(0.074)	(0.101)	(0.075)
Dam-site*treat*after	0.199*	-0.087	0.133
	(0.084)	(0.099)	(0.092)
DOWN*treat*during	-0.044	0.023	-0.005
	(0.036)	(0.029)	(0.046)
DOWN*treat*after	-0.069	0.024	-0.078
	(0.060)	(0.043)	(0.058)
N	13863	13863	13863
Panel B: Log per capita Net Transfers			
UP*treat*during	0.136**	-0.180***	0.018
	(0.051)	(0.047)	(0.066)
UP*treat*after	0.067	-0.046	0.109
	(0.093)	(0.068)	(0.090)
Dam-site*treat*during	0.185**	0.012	0.063
	(0.059)	(0.068)	(0.090)
Dam-site*treat*after	0.166+	0.093	0.105
	(0.092)	(0.100)	(0.108)
DOWN*treat*during	0.007	-0.036	-0.025
	(0.054)	(0.062)	(0.069)
DOWN*treat*after	0.007	-0.066	0.017
	(0.072)	(0.074)	(0.092)
N	9688	9688	9688

Notes: Each column is a separate regression for the dependent variable. Upstream and dam-site coefficients are the linear combination from the regression with downstream set as the default location group. Column (1) reports the original results. Column (2) reports the coefficients when the treatment status of each county were randomly assigned at probability 0.5. Column (3) reports the coefficients when the official dam construction year were randomly assigned following a truncated normal distribution, with the mean, standard deviation, lower and upper bounds set at the original level. All regressions include precipitation and temperature controls, year fixed effects, county fixed effects and provincial trend. Standard errors clustered at dam level in parentheses. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 11: Regression results using the second nearest dam information

	(1) GDP	(2) Gov. Rev	(3) Net Transfer	(4) Population
UP*treat*during	0.024	0.150	-0.067	-0.018*
	(0.036)	(0.102)	(0.042)	(0.006)
UP*treat*after	-0.067*	-0.143+	-0.068	-0.018*
	(0.030)	(0.076)	(0.108)	(0.006)
DOWN*treat*during	-0.017	0.074	-0.079	-0.003
	(0.031)	(0.080)	(0.047)	(0.010)
DOWN*treat*after	-0.058	-0.027	0.057	-0.014
	(0.034)	(0.087)	(0.084)	(0.022)
N	8440	9530	6753	9563
Weather Controls	Y	Y	Y	Y
CFE	Y	Y	Y	Y
YFE	Y	Y	Y	Y
Province Trend	Y	Y	Y	Y

Notes: The outcome variables are logarithm per capita GDP, logarithm per capita governmental revenue, logarithm per capita net transfer and logarithm population in each column. Here counties are matched to the second nearest dam. Downstream counties are included as default group in the regression. The coefficients reported here are the linear combination results for the specific location with downstream region. All regressions include precipitation and temperature controls, year fixed effects, county fixed effects and provincial trend. Standard errors clustered at river basin level in parentheses. Upstream and downstream samples here were restricted to these located within 1000 km away from the dam. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$.

Table 12: River Gradient with Railway and Highway Length

	(1) lnrail	(2) railway	(4) lnhighway	(3) highway
grad (0-1.5%)	0.00149**	0.000416*	0.00173+	0.0113+
	(0.000530)	(0.000156)	(0.000909)	(0.00591)
$\text{grad}_(1.5-3\%)$	0.0138	-0.000523	0.0495**	0.499***
	(0.0116)	(0.00288)	(0.0153)	(0.120)
$\text{grad}_(3-6\%)$	0.0806***	0.0156***	0.0227	-0.235
	(0.0187)	(0.00397)	(0.0229)	(0.174)
$\text{grad}_(> 6\%)$	-0.0480*	-0.0133*	-0.249***	-2.345***
	(0.0229)	(0.00634)	(0.0198)	(0.152)
constant	-1.855***	0.187***	1.873***	9.542***
	(0.203)	(0.0373)	(0.270)	(1.782)
N	31	31	31	31
F	10.91	10.40	416.2	161.0

Notes: The outcome variables are logarithm and level value of railway and highway lengths for each column. Each gradient category explanatory is the percentage of land in that category. The analysis was done for provinces of China in 2010. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$.

Figure 1: Map of dams above 100 meters in China finished or under construction by 2010

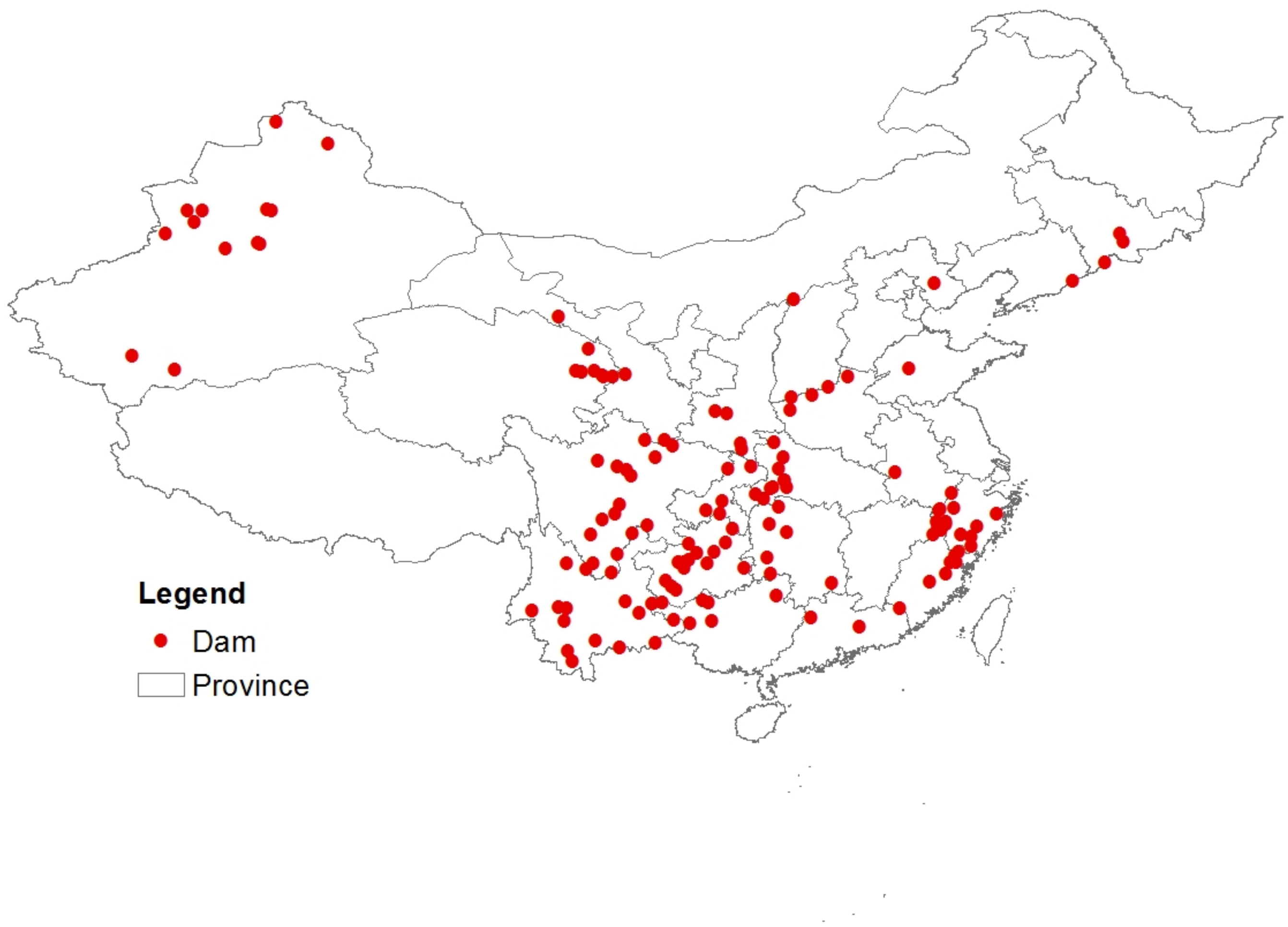
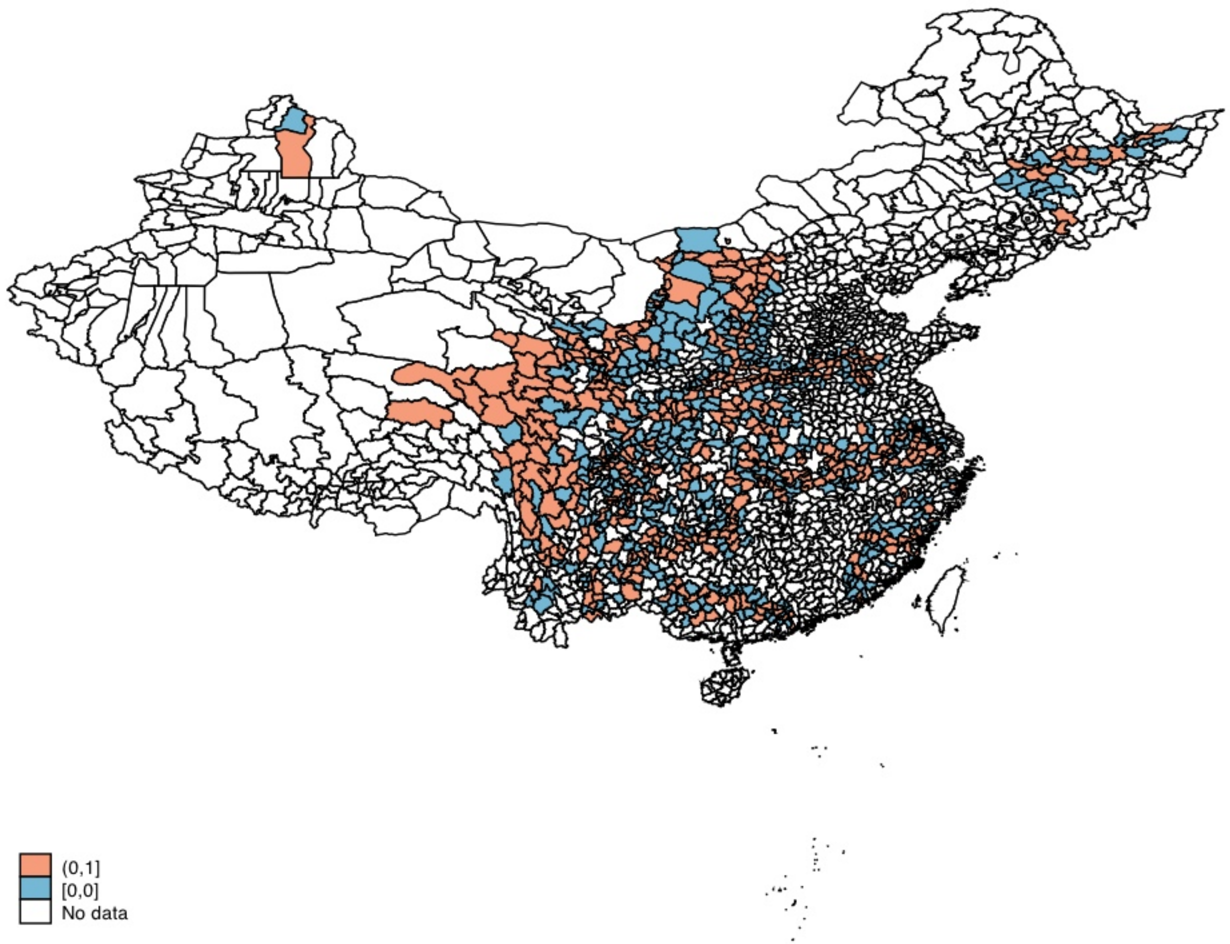
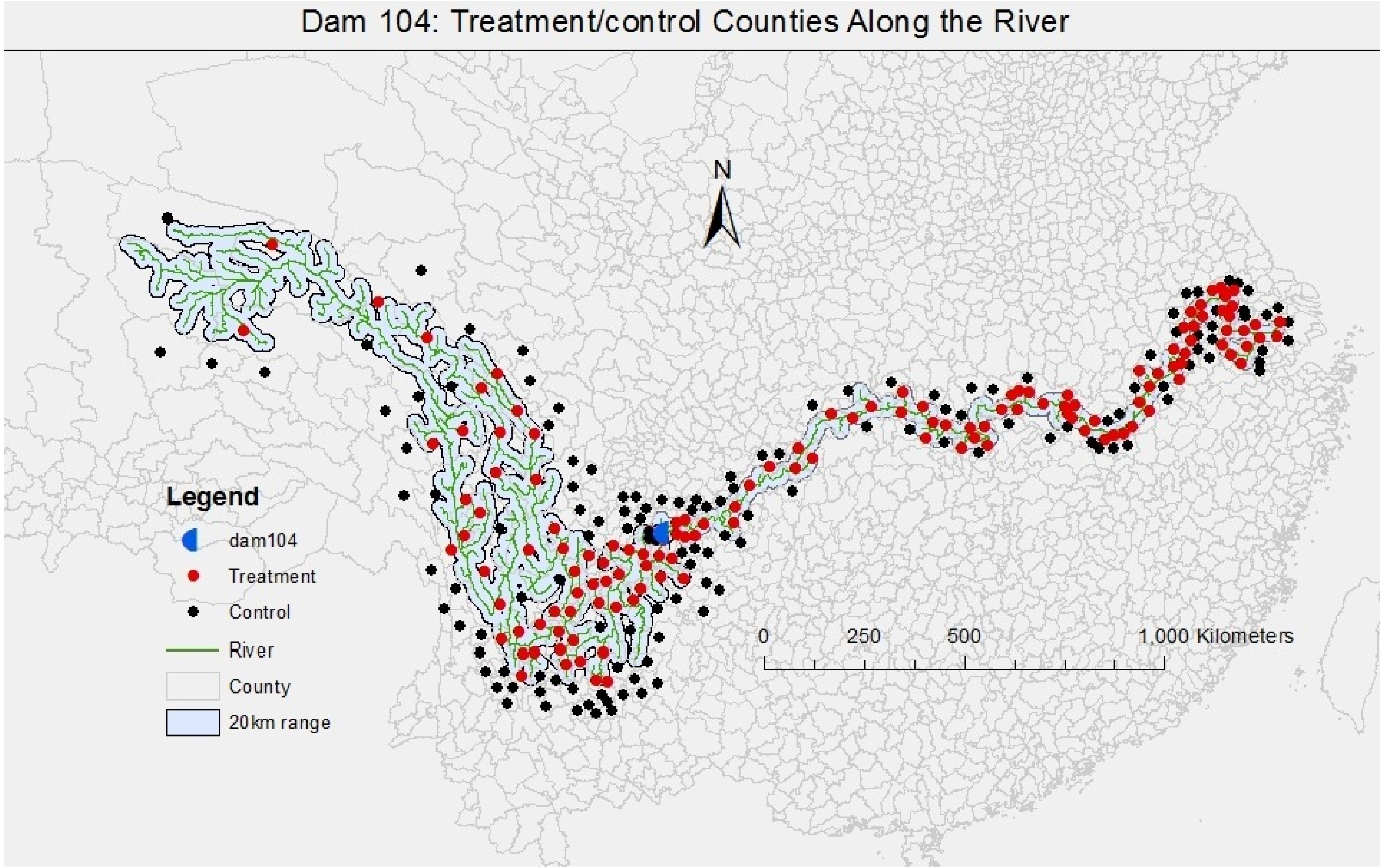


Figure 2: Map of identified treat and control counties



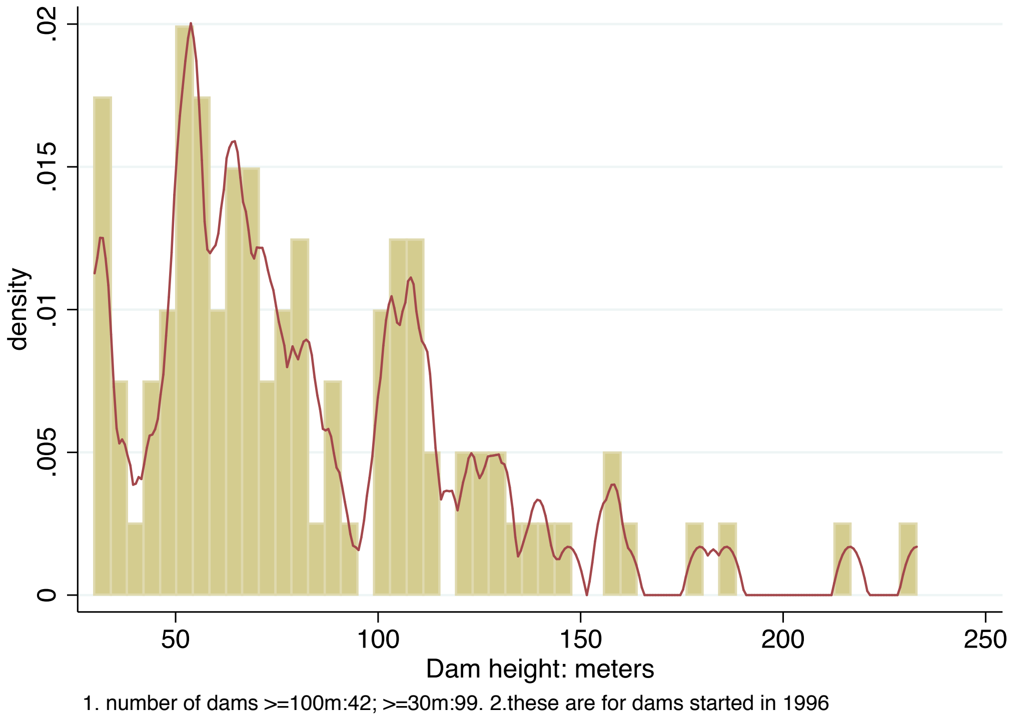
Notes: The orange polygons are treatment counties. The blue polygons are control counties.

Figure 3: Illustration of treatment/control county identification



Notes: This figure illustrates how the treatment and control counties are identified using Dam 104 (Xiangjia Ba Dam) as an example. Black dots are control counties. Red dots are treatment counties. Treatment counties are defined as counties with centroids located within 20km away from the river. Upstream control counties are defined as counties with centroids located between 20 and 100km away from the river. Downstream control counties are those with centroids located between 20 and 50km away from the river.

Figure 4: Distribution for all dams (with construction starting from 1996) above 30 meters in China by 2010



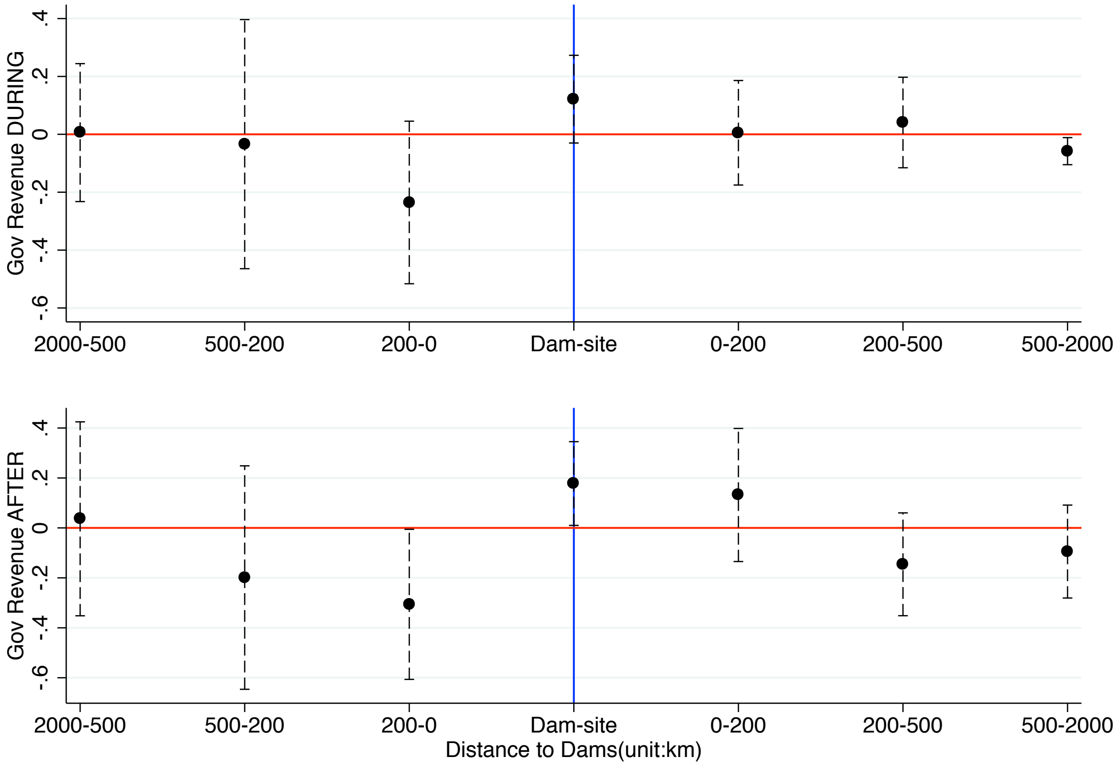


Figure 5: Estimates for Dam Impacts at Various Distance Bins for Governmental Revenue

Notes: The dependent variable is logarithm of per capita governmental revenue. The graph plots out the DID estimates and the 95% confidence interval for governmental revenue at each distance bin. The bins in the left of the "dam-site" regions are upstream counties, while bins in the right of the "dam-site" regions are downstream areas. The top plot reports the estimation results in dam construction periods. The bottom plot reports the estimation results in dam operation periods. The regression model in each distance bin includes provincial year trend, year fixed effects and county fixed effects, with error clustered at dam level.

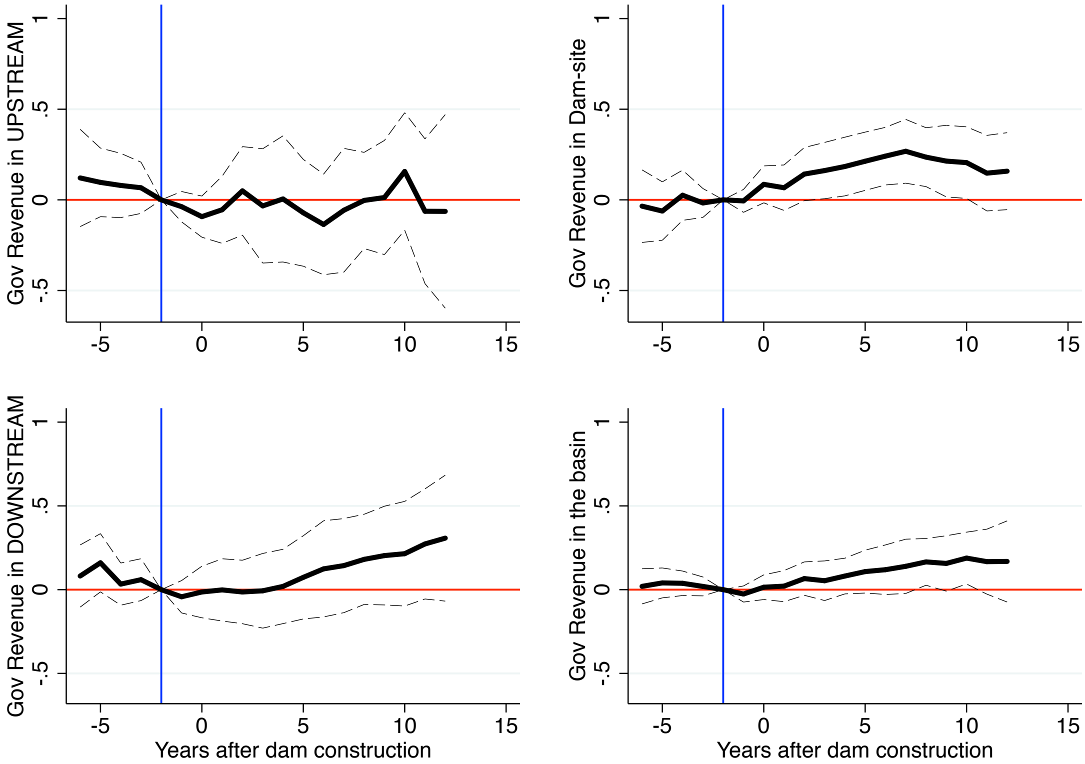


Figure 6: Dam Estimates Over Time for Governmental Revenue

Notes: The dependent variable is logarithm of per capita governmental revenue. The graph plots out β estimates and the 95% confidence interval from the regression equation of $y_{ipt} = \sum_{t=-9...16} \beta_t \text{treat}_i * \text{Dyear}_{it} + \delta X_{ipt} + \rho_t + \lambda_i + \zeta_p t + \epsilon_{ipt}$. Dyear is the normalized year relevant to official dam begin year. In the clockwise direction from the up-left graph, each graph is a separate regression showing the pattern for Upstream, dam-site, The whole Basin and Downstream. Two years before the official dam begin year were used as the default group. Upstream and downstream samples here were restricted to these located within 200 km away from the dam. Standard errors are clustered at dam level.

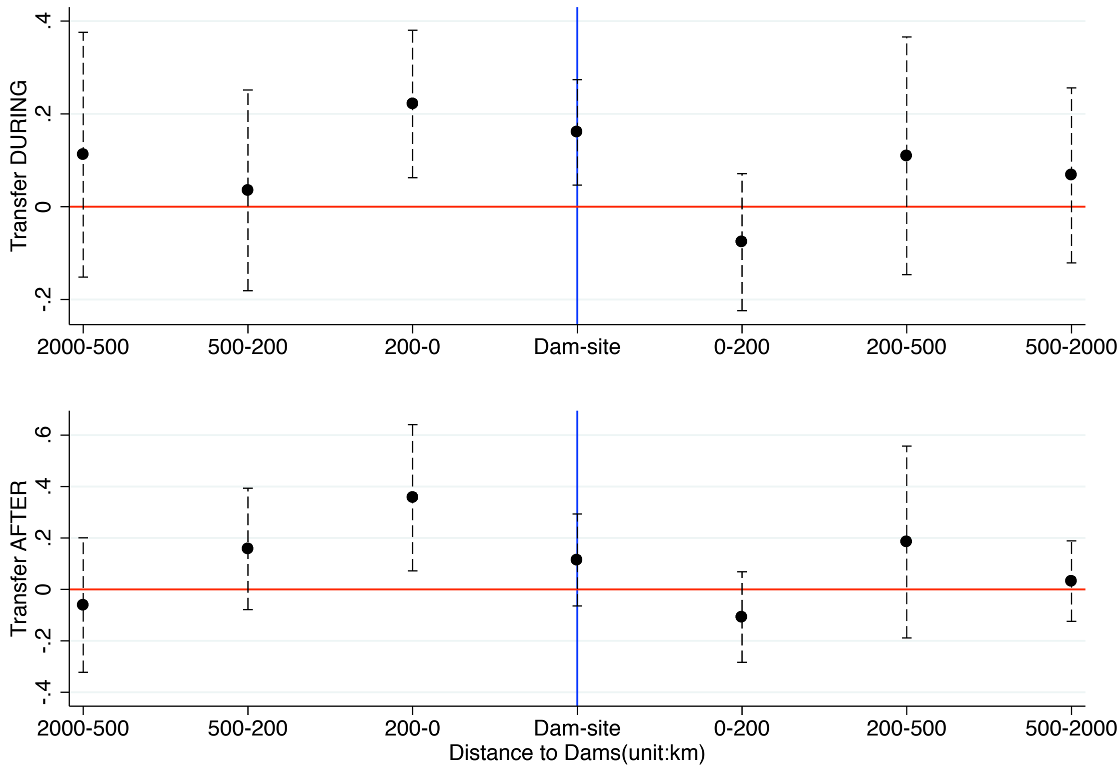


Figure 7: Estimates for Dam Impacts at Various Distance Bins for Net Transfer

Notes: The dependent variable is logarithm of per capita net intergovernmental transfers. The graph plots out the DID estimates and the 95% confidence interval for governmental revenue at each distance bin. The bins in the left of the “dam-site” regions are upstream counties, while bins in the right of the “dam-site” regions are downstream areas. The top plot reports the estimation results in dam construction periods. The bottom plot reports the estimation results in dam operation periods. The regression model in each distance bin includes provincial year trend, year fixed effects and county fixed effects, with error clustered at dam level.

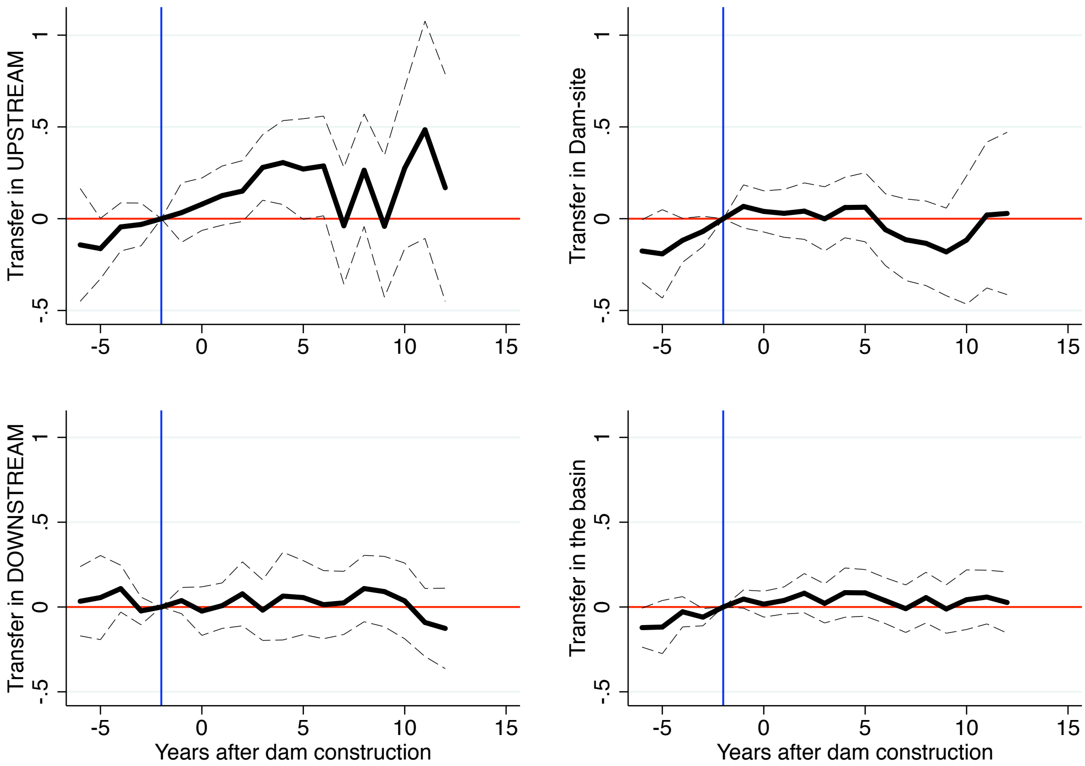


Figure 8: Dam Estimates Over Time for Intergovernmental Transfers

Notes: The dependent variable is logarithm of per capita net intergovernmental transfer. The graph plots out β estimates and the 95% confidence interval from the regression equation of $y_{ipt} = \sum_{t=-9...16} \beta_t \text{treat}_i * \text{Dyear}_{it} + \delta X_{ipt} + \rho_t + \lambda_i + \zeta_p t + \epsilon_{ipt}$. Dyear is the normalized year relevant to official dam begin year. In the clockwise direction from the up-left graph, each graph is a separate regression showing the pattern for Upstream, dam-site, The whole Basin and Downstream. Two years before the official dam begin year were used as the default group. Upstream and downstream samples here were restricted to these located within 200 km away from the dam. Standard errors are clustered at dam level.

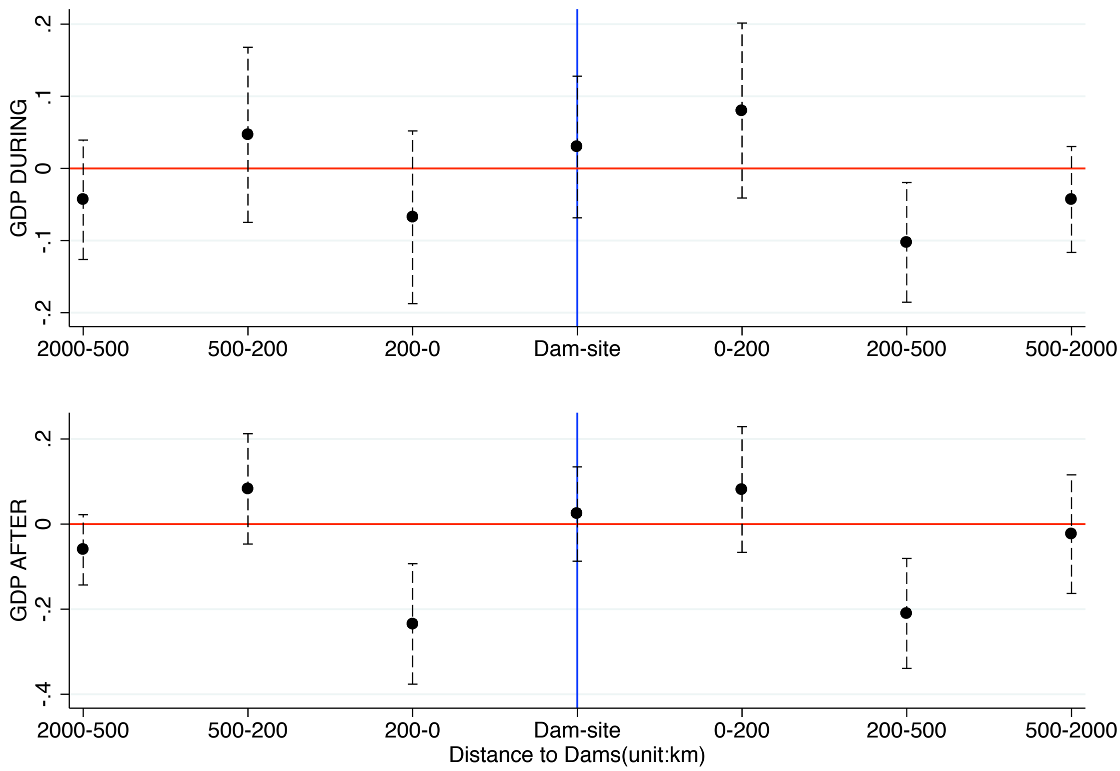


Figure 9: Estimates for Dam Impacts at Various Distance Bins for GDP

Notes: The dependent variable is logarithm of per capita GDP. The graph plots out the DID estimates and the 95% confidence interval for governmental revenue at each distance bin. The bins in the left of the "dam-site" regions are upstream counties, while bins in the right of the "dam-site" regions are downstream areas. The top plot reports the estimation results in dam construction periods. The bottom plot reports the estimation results in dam operation periods. The regression model in each distance bin includes provincial year trend, year fixed effects and county fixed effects, with error clustered at dam level.

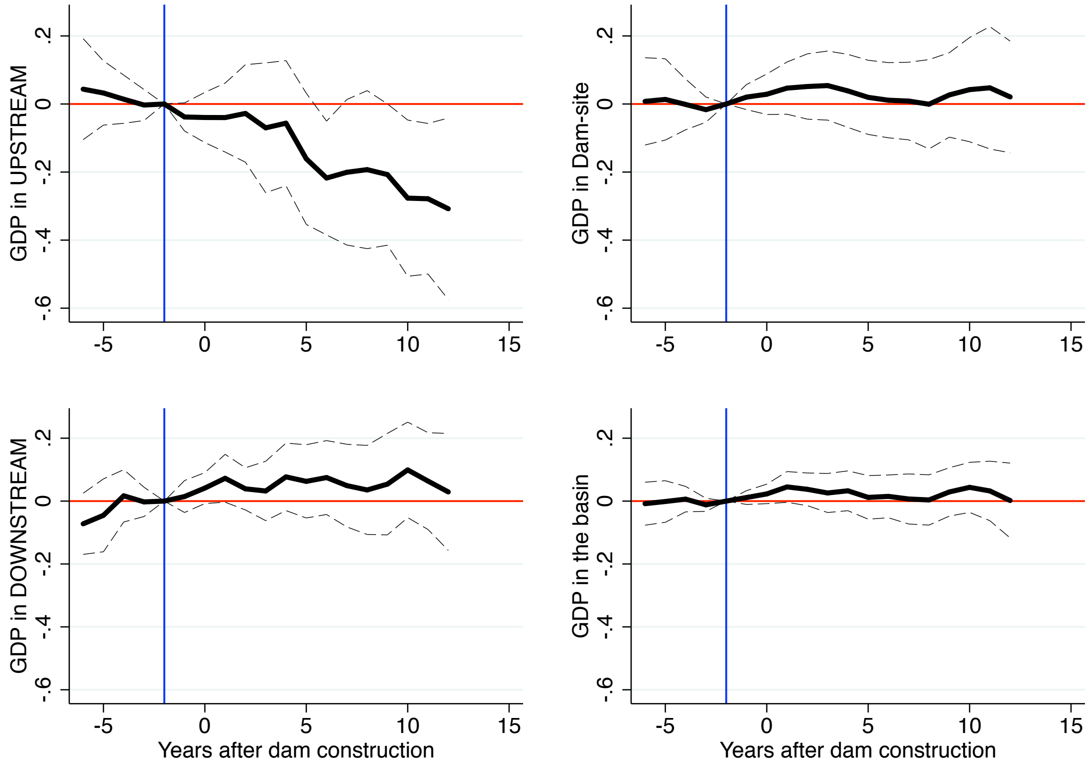


Figure 10: Dam Estimates Over Time for GDP

Notes: The dependent variable is logarithm of per capita GDP. The graph plots out β estimates and the 95% confidence interval from the regression equation of $y_{ipt} = \sum_{t=-9...16} \beta_t \text{treat}_i * \text{Dyear}_{it} + \delta X_{ipt} + \rho_t + \lambda_i + \zeta_p t + \epsilon_{ipt}$. Dyear is the normalized year relevant to official dam begin year. In the clockwise direction from the up-left graph, each graph is a separate regression showing the pattern for Upstream, dam-site, The whole Basin and Downstream. Two years before the official dam begin year were used as the default group. Upstream and downstream samples here were restricted to these located within 200 km away from the dam. Standard errors are clustered at dam level.

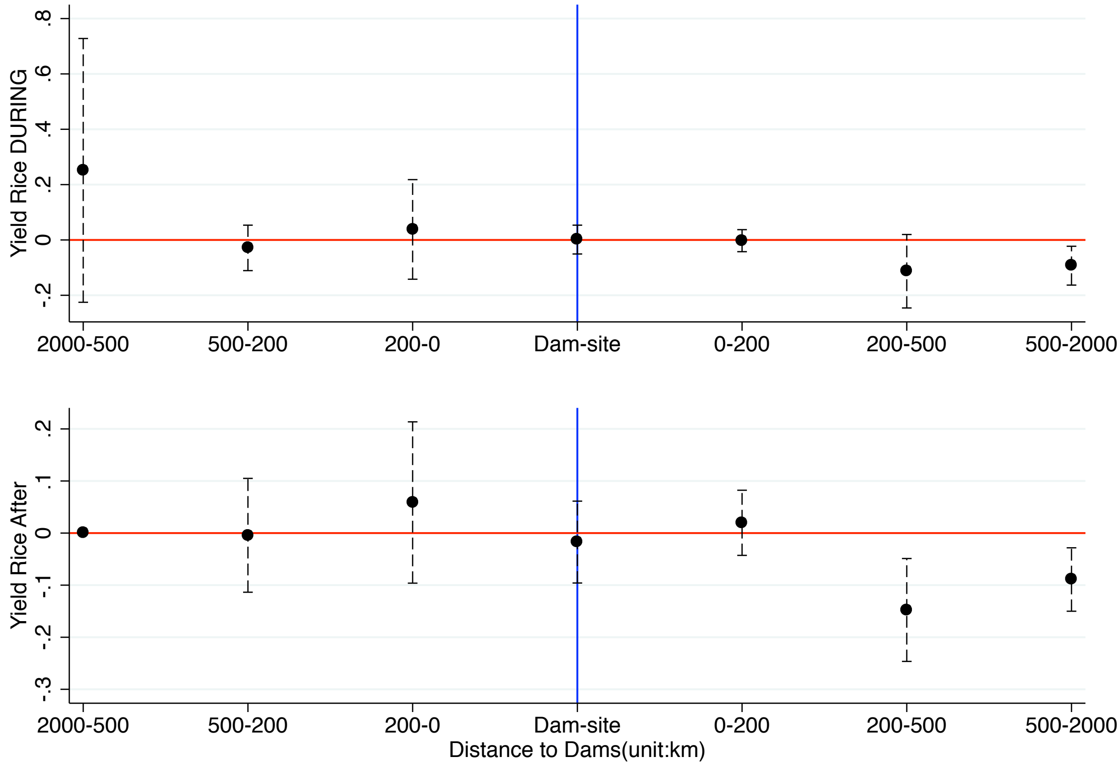
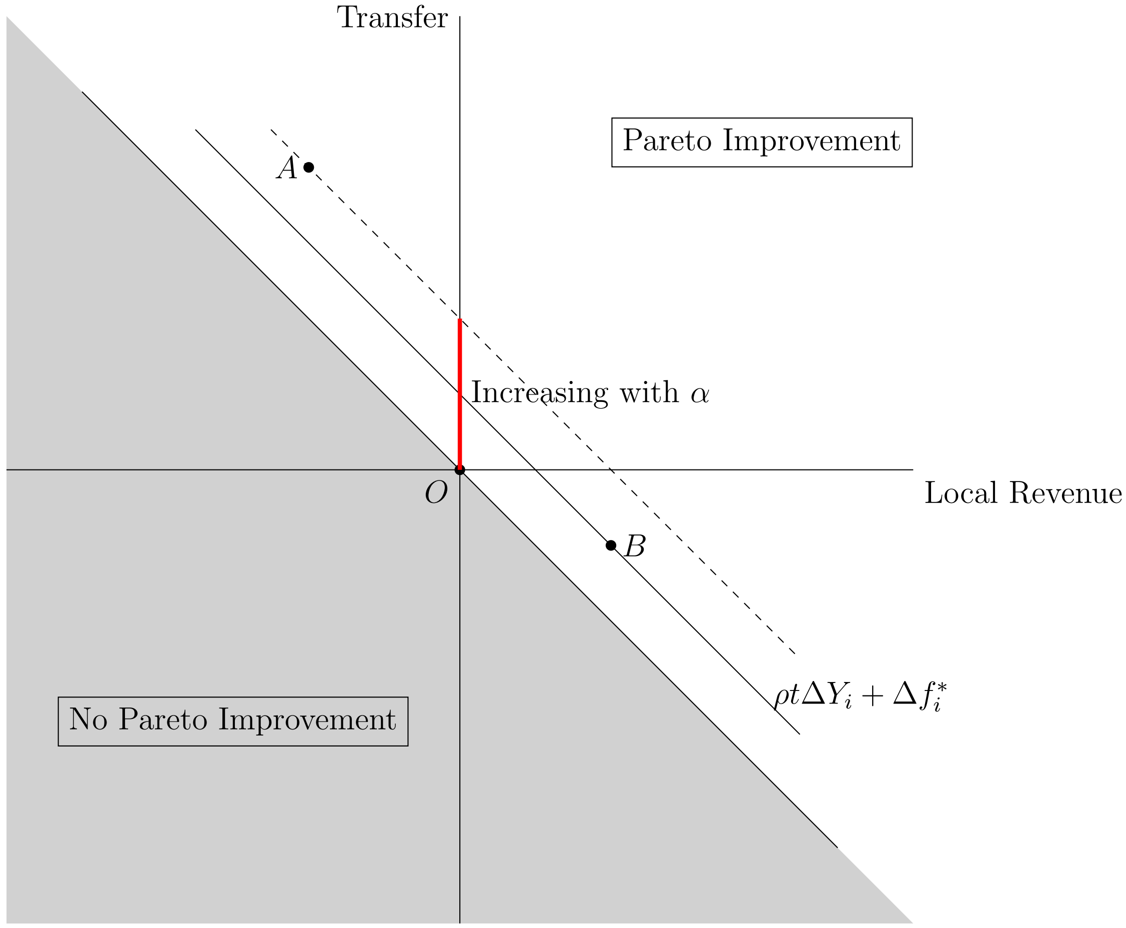


Figure 11: Estimates for Dam Impacts at Various Distance Bins for Rice Yield

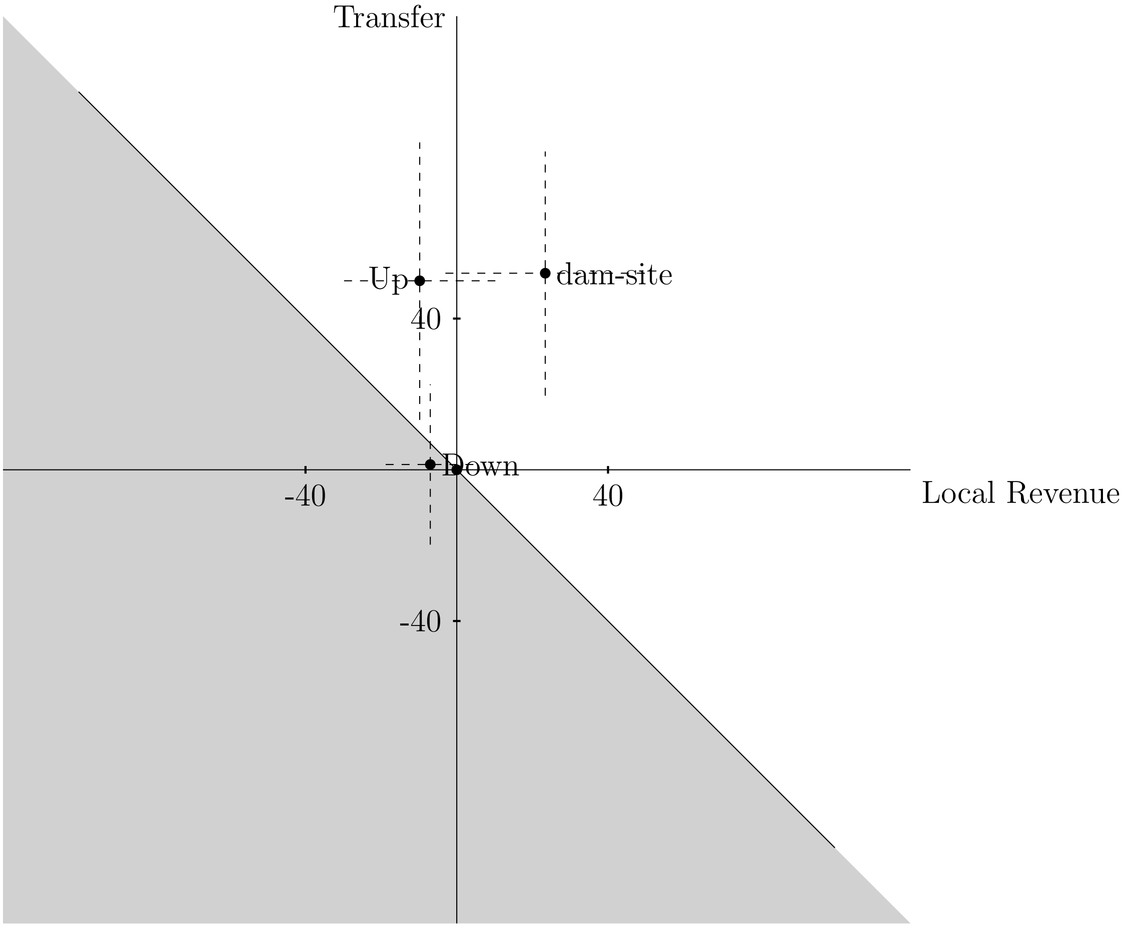
Notes: The dependent variable is logarithm of rice yield. The graph plots out the DID estimates and the 95% confidence interval for governmental revenue at each distance bin. The bins in the left of the "dam-site" regions are upstream counties, while bins in the right of the "dam-site" regions are downstream areas. The top plot reports the estimation results in dam construction periods. The bottom plot reports the estimation results in dam operation periods. The regression model in each distance bin includes provincial year trend, year fixed effects and county fixed effects, with error clustered at dam level.

Figure 12: Graphic Explanation of the Theoretical Model



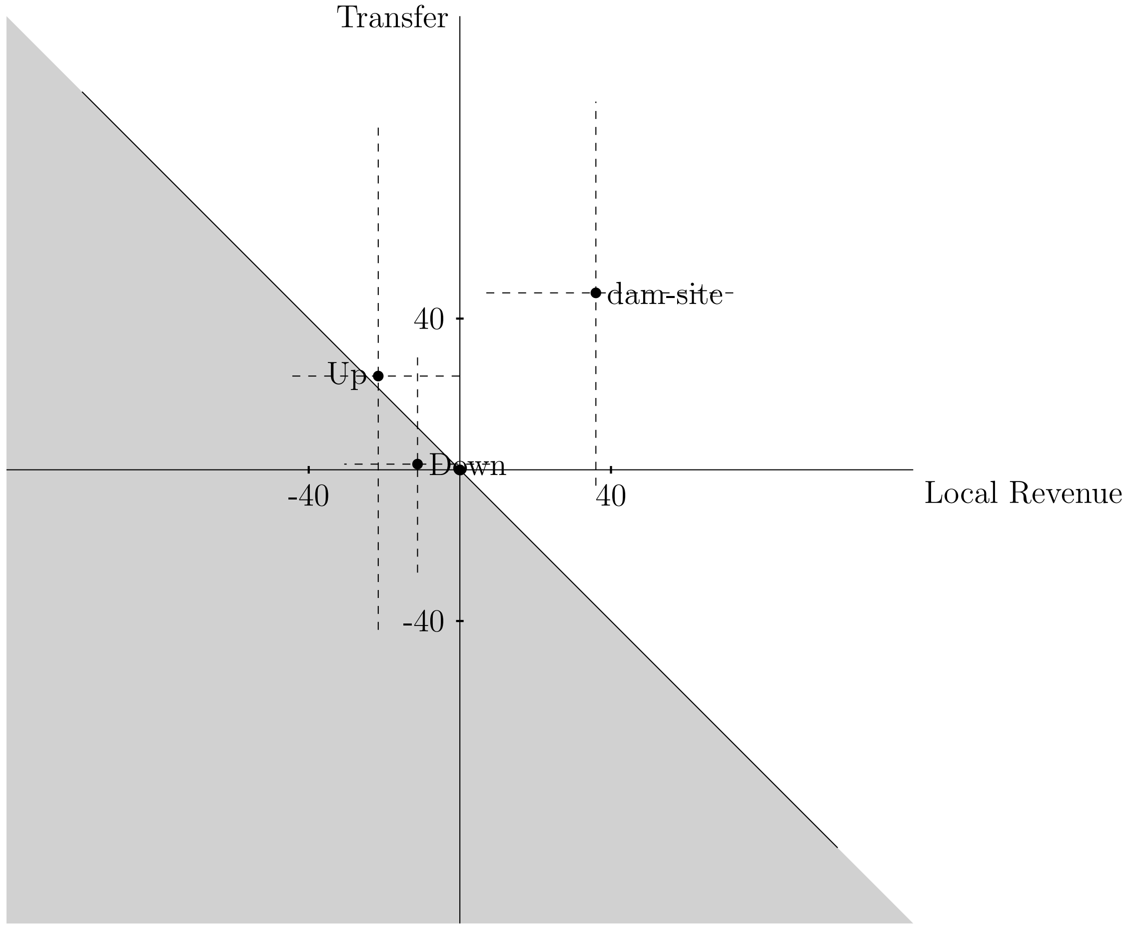
Notes: The comprehensive impacts of dams can push the outcome points away from the original point O to any points in the four quadrants, depending on the combination of changes in governmental revenue and changes in intergovernmental transfer. Points below the diagonal line passing through Quadrant II and Quadrant IV are worse-off outcomes. Above the diagonal line, the farther away a point is from the diagonal line, the better off it will be. The relative distance to the diagonal line represents the wellbeing of local governmental performance. The distance also represents the relative weight of a region in the central decision making process for fiscal resource distribution.

Figure 13: Governmental Pareto Improvement Outcome for Dam Construction



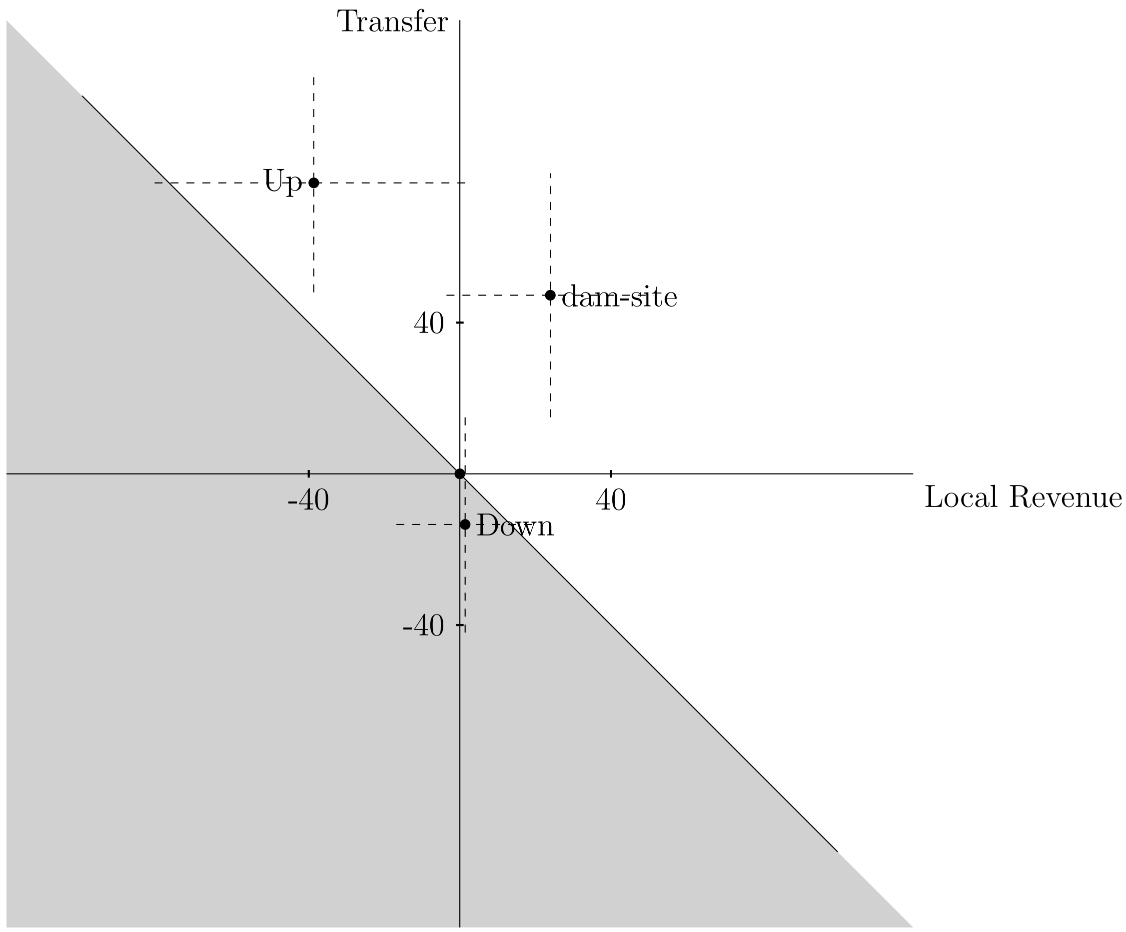
Notes: This figure plots the estimated dam construction impacts on governmental revenue and net transfer for counties at three locations. The value change in revenue and transfer are calculated by multiplying the estimates with the mean value of outcome variables for control counties before dam construction. The horizontal axis represents the changes in governmental revenue, while the vertical axis represents the changes in governmental transfer. The crosses at each point represent the 95% interval for both estimates. The further away the point is from the diagonal axis, the better off a county is.

Figure 14: Governmental Pareto Improvement Outcome for Dam Operation



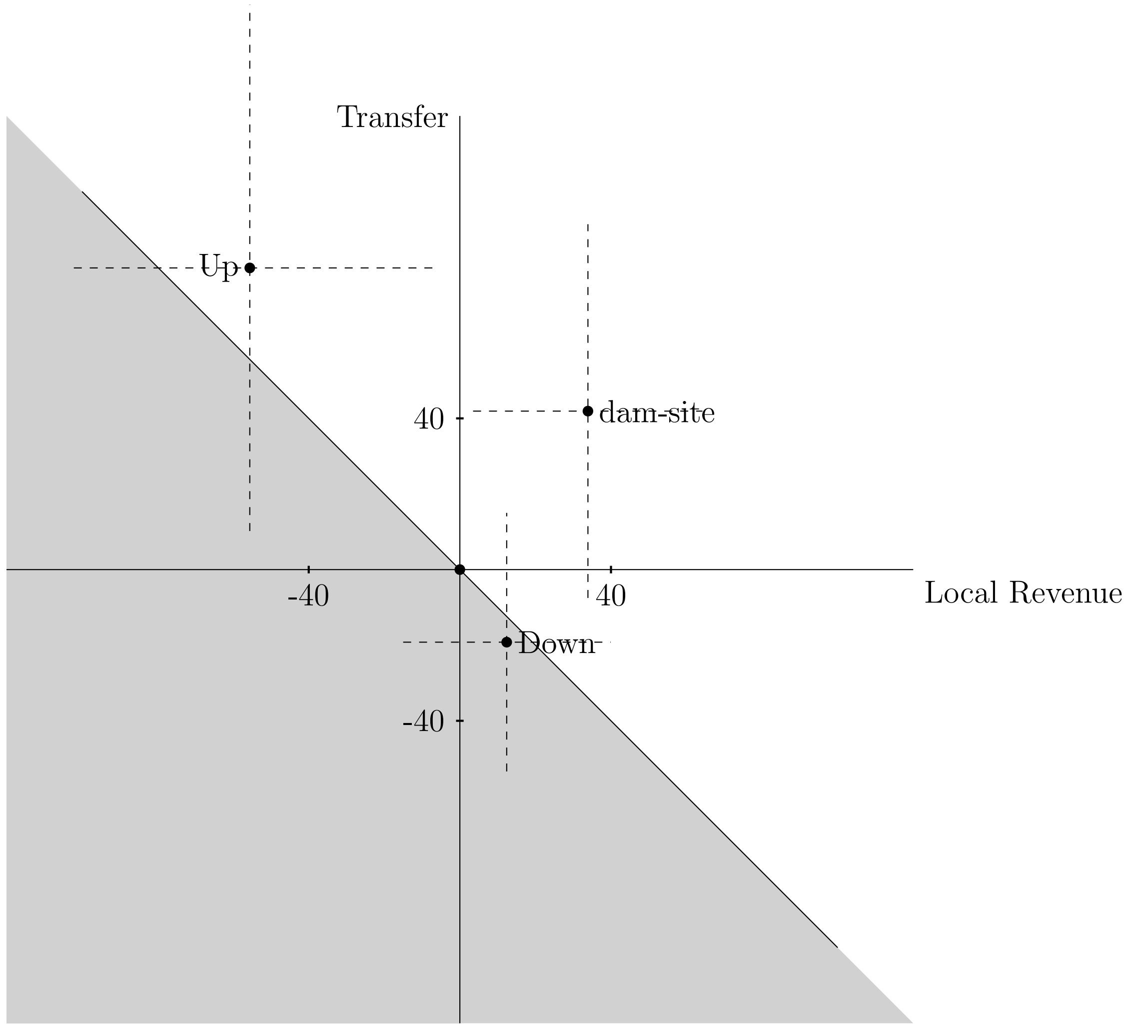
Notes: This figure plots the estimated dam operation impacts on governmental revenue and net transfer for counties at three locations. The horizontal axis represents the changes in governmental revenue, while the vertical axis represents the changes in governmental transfer. The crosses at each point represent the 95% interval for both estimates. The further away the point is from the diagonal axis, the better off a county is.

Figure 15: Governmental Pareto Improvement Outcome for Dam Construction (within 200km)



Notes: This figure plots the estimated dam construction impacts on governmental revenue and net transfer for counties within 200km away from the dam site, based on the estimated results from logarithm outcome variables and the mean values of dam-treated counties in the three locations. The horizontal axis represents the percentage changes in governmental revenue, while the vertical axis represents the percentage changes in governmental transfer. The crosses at each point represent the 95% interval for both variables. The farther away the point is from the diagonal axis, the better off a county is.

Figure 16: Governmental Pareto Improvement Outcome for Dam Operation (within 200km)



Notes: This figure plots the estimated dam operation impacts on governmental revenue and net transfer for counties within 200km away from the dam site, based on the estimated results from logarithm outcome variables and the mean values of dam-treated counties in the three locations. The horizontal axis represents the percentage changes in governmental revenue, while the vertical axis represents the percentage changes in governmental transfer. The crosses at each point represent the 95% interval for both variables. The farther away the point is from the diagonal axis, the better off a county is.