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# Transport infrastructure connectivity and conflict resolution: a machine learning analysis

Ji Luo[1] · Guijun Wang[2] · Guangqin Li[3] · Greta Pesce[4]

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**Abstract**
Transport infrastructure connectivity (TIC) has strong endogeneity issues, making it difficult to directly assess its impact on local conflict resolution. This study presents new evidence of the effects of TIC on conflict resolution by conducting a natural experiment and applying machine learning methods to overcome the endogeneity issue. Based on global conflict data from 2010 to 2017, the empirical results show the following: (1) TIC can significantly improve countries' global ranking for conflict resolution; in particular, the marginal benefit of developed countries is greater than that of developing countries. (2) The mechanism behind this effect is the promotion of trade facilitation, a more balanced employment ratio across genders, and improved income levels through TIC, which further enhances the conflict governance capacity of countries. In light of the findings, policy-makers should consider the opportunity to combine TIC with greater security for the realization of economic and social benefits, taking into account the significant opportunities for developing countries and the importance of balance across genders and income levels.

**Keywords** Transport infrastructure connectivity · Conflict resolution · Difference-in-differences model · Machine learning

## 1 Introduction

On May 10, 2020, the first multi-span rigid frame continuous beam for the No. 2 Bridge of Indonesia's Jakarta-Bandung High Speed Railway was successfully completed. The railway which connects the capital of Indonesia with Bandung, the country's fourth largest city, is 142.3 km long, accounting for 61.6% of the total length of the project, and is worth $5.5 billion. The railway reduces the travel time between the two cities from approximately three hours by car to just forty minutes [9]. This high-profile project represents an ambitious infrastructure development plan but has also been plagued by issues such as its questionable benefit and the numerous challenges related to the territory's geography and densely populated areas.

This story is just one of thousands from the Belt and Road Initiative (B&R) initiated by China in 2013, which has heavily invested in a variety of infrastructure projects to strengthen the economic capacity and connectivity between the 65 involved nations in Asia, Africa, and Europe [10]. On the one hand, B&R has been welcomed by developing countries, where it has also received significant media coverage in the hope that the project will fill their lack of infrastructure and resources. On the other hand, B&R is not as popular in countries with more advanced economies. In these countries, B&R has been criticized particularly regarding the sustainability of its development model that would increase connectivity through the construction of significant infrastructure in countries characterized by internal conflicts and instabilities, resulting in an increase in costs and risks [5] (Fig. 1).

B&R effectively illustrates the complexity of the relationship between transport infrastructure connectivity and conflict resolution that our research aims to solve. Transport infrastructure connectivity (TIC) means investments,

✉ Guangqin Li
2014210132@mail.buct.edu.cn

[1] The School of Public Policy and Management, Tsinghua University, Beijing, China

[2] The School of Economics, Peking University, Beijing, China

[3] School of International Trade and Economics, Anhui University of Finance and Economics, Bengbu, China

[4] The School of International and Public Affairs, Shanghai Jiao Tong University, Shanghai, China

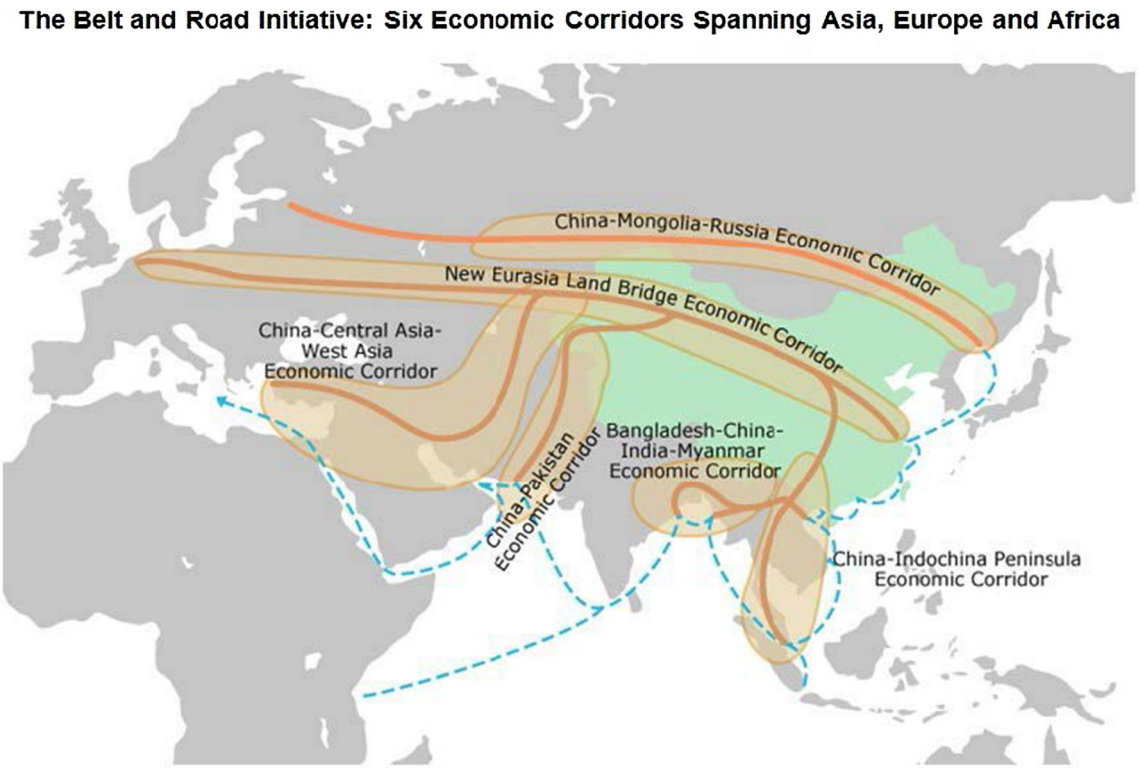


**Fig. 1** The roadmap of B&R infrastructure connection. Source: HKTDC Research, http://china-trade-research.hktdc.com/business-news/article/One-Belt-One-Road/The-Belt-and-Road-Initiative/obor/en/1/1X000000/1X0A36B7.htm

construction, and supply of transport, such as roads, railways, ports, air transport, and energy and communication facilities, at national and international levels [46, 47]. In contexts that face the risk of conflicts, infrastructure access is necessary to restore economic growth and generate the preconditions for peace and investment [34]. Hence, TIC has emerged as an overarching investment priority among governments facing the threat of conflict and terrorism [2].

Conflict resolution reflects the alleviation of local, regional, and international terrorism and conflict activities, the contribution of peace and stability maintenance, and improved conflict governance capacities [39]. As highlighted by most of the literature on conflict resolution, it is crucial that infrastructure providers decrease the likelihood of a return to conflict, and thus it is important that key infrastructure providers in conflict scenarios are aware of the causes of conflict. Infrastructure providers should work on the assumption that hostilities have not ended and determine their responses to situations of conflict [30]. This understanding of the operational environment ensures that appropriate planning for TIC is devised to mitigate potential problems that could spark a return to hostilities and create further insecurity [30].

The peacebuilding literature can broadly be broken down into three separate fields, specifically, the relationship between policing costs and the presence of infrastructure, the cross-border cooperation between European countries and the multilateral infrastructures initiatives in Asia. The literature broadly developed over the period 1979–2020, with the largest number of contributions being made in the last decade. The relationship between policing costs and the presence of infrastructure generally focuses on the fact that developing effective infrastructures has a considerable impact on safety, economic, and environmental policies.

The researches about the cross-border cooperation between European countries concentrate on the positive contribution of border infrastructures to economic and social sustainable development. The studies on the multilateral infrastructures initiatives in Asia bring the recent trends in regional and inter-regional integration into focus, which is associated with multilateral infrastructure connectivity initiatives, such as B&R and the Partnership for Quality Infrastructure [35].

This study presents new evidence of the effects of TIC on conflict resolution: While it is widely assumed in other studies that TIC has an unclear effect on local conflict resolution [8], this paper presents the downside by conducting a natural experiment and applying machine learning methods to overcome the endogeneity issue.

TIC is a double-edged sword in terms of conflict resolution. On the one hand, TIC can provide job opportunities, increased income, and trade facilitations in countries that have experienced conflicts, consequently boosting the

economy [3]. On the other hand, TIC may also have perverse effects, providing violent militias easier access to vulnerable and remote communities or tempting subsistence farmers to join the militias [8]. Indeed, it must be recognized that TIC for conflict resolution is not generic but heterogenic: The response to this risk involves identifying the appropriate financial, administrative, and technical skills and restoring the most needed infrastructure services.

In light of these facts, this paper aims to fill the academic gap related to three main issues. First, this paper takes a position in the dispute over the two-edged effects of TIC in the peace and stabilization process. In particular, contrary to Jones and Howarth [22], this paper provides evidence that although the fact that weak domestic governance and insecurity are the main drivers of conflicts, TIC may have a highly positive effect through international cooperation by focusing on the correct underlying causes of conflict resolution.

Second, this study attempts to obtain answers by comparing developing and developed countries to highlight the importance of sound institutions in conflict resolution. In effect, as conflict-affected countries suffer from disproportionately low levels of private investments in infrastructures, only small-scale service providers are likely to emerge during conflict [42]. Although some countries have been able to couple aggressive reform and liberalized policies to abate infrastructure investment conflict, it remains unclear how they can bridge TIC with their neighbors while preserving their domestic stability.

Finally, this study takes into account that infrastructures and other related trade costs affect conflict incidence when conflict selection is endogenous; thus, resolving the endogeneity of transport costs and conflict is a key issue [11]. Some scholars use instrumental variables (such as the natural-historical path, ethnic fractionalization or distance to the border) and find that the intensity of conflict can dampen the beneficial impacts of infrastructure connectivity on welfare [2]. However, instrumental variables cannot completely overcome the heterogeneity of circumstances in different countries and identify actions that jointly target governance and infrastructure activities. Instead, this paper adopts machine learning to clarify the counterfactuals of TIC on conflict resolution and provides more persuasive evidence for its function and mechanism.

## 2 Hypothesis

The security risks brought by terrorism and regional conflicts significantly affect the geopolitical and economic patterns among countries. Thus, it is important to assess both the direct impacts of conflict and infrastructures and their combined effect.

Infrastructure can be damaged in conflicts, and reconstructing infrastructure is often essential to sustain recovery. Conflicts erode governance institutions, weaken public expenditure management systems, and increase transaction costs, making it difficult for principals to monitor their agents. Drawing on evidence from evaluation studies, a number of policy tensions and action points for policy-making in infrastructure sectors in post-conflict contexts are identified.

Considering these facts, we propose Hypothesis 1:

Hypothesis 1: TIC could significantly promote conflict resolution.

At present, although the world economy has overall made great progress and the income levels of developing countries have achieved a rapid growth, a large global gap still exists between the rich and the poor [29]. In effect, many developing countries have seen the number of poor increasing annually, creating conditions for widespread discontent in society and a fuse for igniting terrorist activities [44].

Generally, developed countries receive greater marginal utility for development from social peace and stability, that is, the marginal cost and sunk cost of conflict, as represented by economic damage, are higher [12]. For instance, an increase in the perceived level of terrorism was responsible for the drop in FDI and capital markets in the United States that followed the events of September 11 [1].

The effect of poor socioeconomic conditions on conflict is relevant only after a certain development level has been reached; hence, a distinction between developed and developing countries should be considered [15]. Developed countries are more inclined to improve residents' living standards, build inclusive cultural patterns and reduce violent conflicts through international economic cooperation and connection, not only contributing to regional peace but also promoting broader sustainability through spillover effects [21].

In contrast, conflicts in developing countries have often been organized along ethnic lines. Specifically, many conflicts appear to be largely ethnic, geographic, and religious in nature, whereas an outright economic class struggle is relatively rare [14]. The possibility of class-driven conflict does not preclude the existence of other sources of social discontent. Similarity can be directly conflictual when resources are limited and economic change is unevenly distributed—possibly relevant even for developed countries, but it is a first-order consideration in developing countries [40].

Thus, TIC in developing countries is easier destruct as soon as it has been constructed when conflict and war

occur, making these countries "throw the handle after the blade" in view of TIC. Hence, we propose Hypothesis 2:

Hypothesis 2: Compared with developing countries, developed countries are more affected by TIC on conflict resolution.

The two-way causal relationship between trade and conflict activities must also be considered [32]. TIC can indirectly affect conflict resolution through its impact on the amount of trade that occurs. Whether the negotiation regards goods, services, manufacturing exports, or logistics performance, representing the quality of trade-related infrastructure will affect bilateral trade volume, whereas infrastructure construction will improve the net trade in goods and services, the quality of trade-related and transport-related infrastructure, and the manufacturing export share by improving trade facilitation [27]. The percentage of export and other indicators further reflects the level of governance over local violent conflicts. Although trade and FDI have no direct impact on conflict activities, they can indirectly and positively affect conflict governance by promoting economic development. Therefore, we propose Hypothesis 3:

Hypothesis 3: Trade facilitation has a positive, mediating effect on the effect of TIC on conflict resolution.

Another aspect is that a high unemployment rate means that more people with a higher education level are attracted to and participate in terrorist activities, improving their quality [4]. Using a mixed effects Poisson regression model, Freytag et al. [15] show that unfortunate socioeconomic conditions such as high unemployment are suitable to reducing the opportunity cost for potential terrorists and increasing the likelihood of terrorist attacks originating from a specific country.

Although the existing empirical literature shows that unemployment may not correlate with the quantity of the conflict [26], the theory predicts that unemployment may affect the quality of conflict. In addition, a consideration of gender differences shows that women in many countries are regarded as the "reserve forces" of labor in the family. When more jobs are provided, women walk out of families and jump into labor markets [20]. A close relationship exists between the traditional norms of social behavior and women's gender roles: To some extent, the social norms of behavior are more inclined to involve women into conflict activities under the constraints of morality, patriarchy, family pressure, and the maintenance of chastity [43].

Consequently, we believe that an increase in male employment has a weaker spillover effect on the work–leisure time ratio, and the marginal utility of its promotion of social stability is lower than that of an increase in female employment, which leads to the limited impact of male employment on violent conflicts.

An increase in female employment helps reduce the probability of conflicts more than an increase in male employment, and we propose Hypothesis 4:

Hypothesis 4: Employment across gender has a differential mediating impact on the effect of TIC on conflict resolution.

It must be specified that poverty does not necessarily breed terrorism but might create a hotbed for its growth [25] because it encourages terrorists to carry out destructive activities and seriously damages the local economy [38].

Hence, cooperation in creating TIC could create more jobs at the local level, raise incomes, enable more local residents to enjoy income premiums, and improve living conditions, which could further keep residents away from terrorist activities and conflicts. Because income inequality indirectly affects terrorist activities by weakening institutions and a reasonable secondary distribution of income can effectively reduce terrorist activities [13], we propose Hypothesis 5:

Hypothesis 5: Income growth has a positive mediating effect on the effect of TIC on conflict resolution.

## 3 Methodology

### 3.1 Data

The present research used secondary data from the 2019 Global Justice Index Report of the Fudan University Institute of Social Sciences, the UCDP (Uppsala Conflict Data Program) armed conflict database, World Bank Indicators, the Human Development Index from United Nations Development Program, the Global Peace Index from the Australian Institute for Economics & Peace, and other sources. The data were for the 2010–2017 period. Our collected sample is at the country level, which includes 192 countries and regions globally.

### 3.2 Variables

The main dependent variable in this paper is *Conflict*, which indicates the ranking of global conflict and terrorism governance contribution. The source of the *Conflict* measurement is the 2019 Global Justice Index Report of Fudan University Institute of Social Sciences. Given the interaction of conflict ranking among countries, which may cause estimation bias, we also use other indexes (absolute score of Global Peace Index) for a robustness check to measure

**Table 1** Data sources for conflict governance

| Category | Dimension | Index | Data source | Coverage |
|---|---|---|---|---|
| Performance | Terrorism and conflict | Conflict number | UCDP armed conflict database and the dataset on war-related deaths; UCDP global terrorism database | 2010–2017 192 countries |
| | | War number | | |
| | | Conflict death number | | |
| | | Terrorism incident number | | |
| | | Terrorism death number | | |
| Contribution | Conflict agreement | Number of agreements achieved | UCDP peace agreement database | |
| | | Concrete results of agreements | | |

Source: The Global Justice Index Report of Fudan University Institute of Social Sciences in 2019, https://globaljustice.fudan.edu.cn/Global/index/191317619358

*Conflict*. The specific calculation of the Global Justice Index Report indicators is in Table 1.

Based on the data and indicators recognized both in academia and in practice, this report attempts to measure the impact of various countries on global justice in the field of terrorism and armed conflict resolution. Impact will be measured based on performance and contribution. Performance is a negative measurement that captures the extent to which a country is involved in terrorist attacks and armed conflicts; that is, the higher the degree of involvement is, the greater the negative impact on global justice. Five indicators are used to measure this category: (1) the number of conflicts; (2) the number of wars; (3) the number of deaths caused by conflicts; (4) the number of terrorist incidents; and (5) the number of deaths caused by terrorist incidents. The contribution captures the effort a country has made to reduce conflict and promote peace. Two indicators are used to measure this category: (1) the number of agreements reached and (2) the concrete results of these agreements.

The armed conflict data are from the UCDP (Uppsala Conflict Data Program) armed conflict database and the dataset on war-related deaths. The data on the agreement are based on the UCDP peace agreement database. Terrorism-related data are from the UCDP global terrorism database. These data resources are highly praised and widely used in the field of conflict- and terrorism-related research. Our concepts of terrorism and armed conflict are also derived from the authoritative definition of these databases. Other covariate data are from the World Bank. Due to the endogeneity concerns, all covariates are lagged for one year and then matched with the dependent variables.

TIC in different countries. Cause we use natural experiment and Difference-in-differences (DID) model in our paper, we take the intersection of the policy year and the policy treatment group as the measurement of the policy implementation of TIC.

Due to the high dimensionality of World Bank indicators, we use a Lasso penalized regression to reduce the dimensionality of control variables. First, we delete all covariates (eigenvectors) with a sample of less than 100 and replace the missing values of other covariates from the World Bank with 0. There were 1880 remaining covariates, and 1520 samples. We use conflict rank as the dependent variable and all covariates as the explanatory variables to conduct the lasso regression. Through tenfold cross-validation and 100 iterations, the results showed that the optimal value of $\lambda$ was 11.533, and there were 11 covariates whose coefficients were significantly different from 0. We use these covariates as the control variables in the DID model.

### 3.3 Model

The implementation of B&R on TIC can be used as a natural experiment to overcome the endogeneity issue. If we assume that the policy is exogeneous, we could view it as a natural experiment for infrastructure connectivity and run the DID model: the treatment group in the experiment are countries along the B&R (65 countries; see the appendix), and the control group is the rest of the countries throughout the world that are not along B&R (approximately 120 countries); the experimental time node is 2013—when B&R was proposed.

Hence, the main basic empirical equation is a DID model:

$$\begin{aligned}\text{Conflict}_{it} = {} & a + aB \text{ and } R\text{year} + aB \text{ and } R\text{country} \\ & + a\text{Infrastructure}_{it} + \beta X_{it} + \text{year}_t + v_i + \mu_{it}\end{aligned} \tag{1}$$

where $i$ and $t$ represent country and time respectively; Conflict represents conflict resolution; $B$ and $R$year represents the proposed year of the B&R (if after 2013, set to 1; otherwise set to 0); $B$ and $R$country represents the countries along the B&R (if along the B&R, set to 1; otherwise, set to 0); *Infrastructure* represents TIC (the intersection of

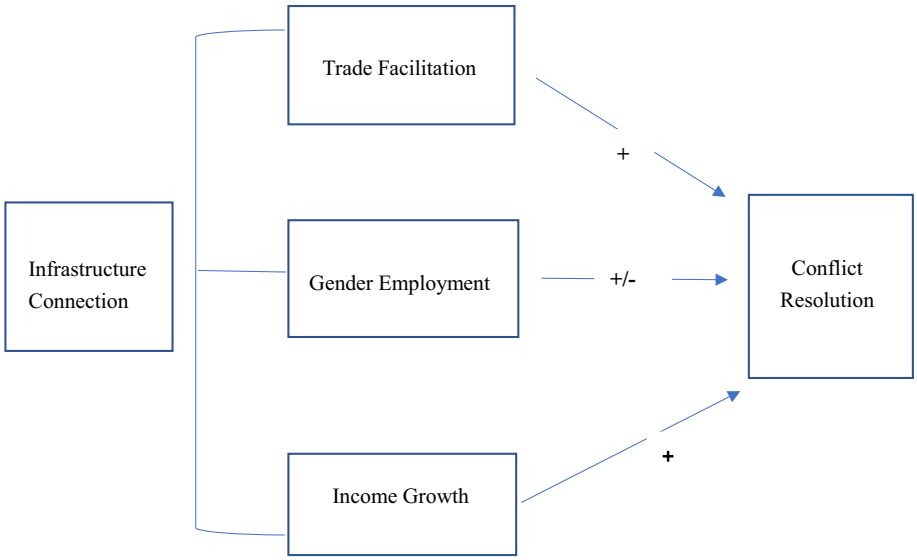


**Fig. 2** The theoretical framework of infrastructure on conflict resolution. Note: " + " indicates positive impact, "−" indicates negative impact

Note: "+" indicates positive impact, "-" indicates negative impact.

$B$ and $R$year and $B$ and $R$country); $X$ are the control variables; $year_t$ is the time fixed effect; $v_i$ is the individual effect; and $\mu_{it}$ is the residual (Fig. 2).

## 4 Empirical analysis

### 4.1 Parallel trend test

Figure 3 shows the parallel trend test of the ranking in conflict governance between the treatment group and the control group for 2010–2017, in which the vertical coordinate is the rank value (the smaller the rank value is, the higher the rank is, and the greater the contribution to global conflict governance), and the horizontal coordinate is time.

Figure 4 is the dynamic effect diagram of the time coefficient. The vertical coordinate is the global contribution rate of conflict, and the horizontal coordinate is the time coefficient. It can be found that the time coefficient fluctuated in a range of approximately 15 before the policy was proposed in 2013. After 2013, the time coefficient decreased significantly, and it continued to maintain a downward trend through 2017, proving the robustness of the parallel trend (Fig. 5).

In 2010–2017, the threat of terrorism and armed conflict were a continuous concern, which had a significant impact on global justice. In terms of the most recent ranking results in 2017, China has jumped to the top in terms of the governance of terrorism and participation in international peace agreements, rising from 11th in 2014 to 1st in 2016 and 2017. This is related to the trend of China's peaceful rise and active participation in global public affairs.

### 4.2 Basic DID

Due to the high-dimension of World Bank indicators, we use Lasso penalized regression to reduce the dimension of

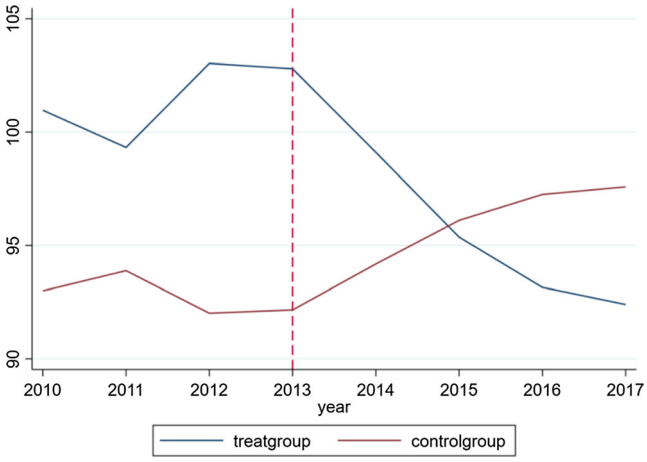


**Fig. 3** Parallel trend test

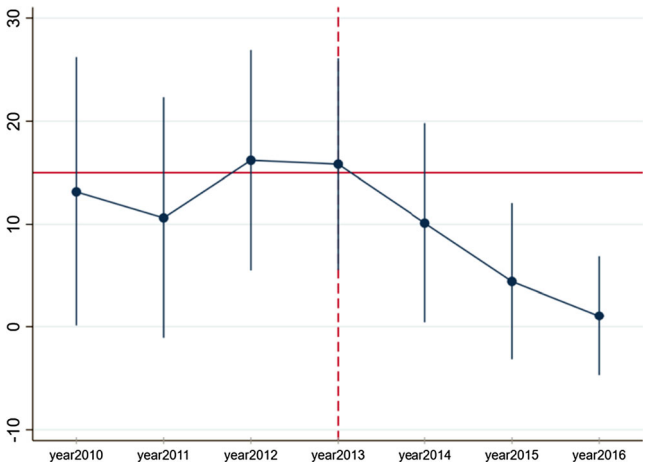


**Fig. 4** Dynamic effect of time coefficients on conflict resolution

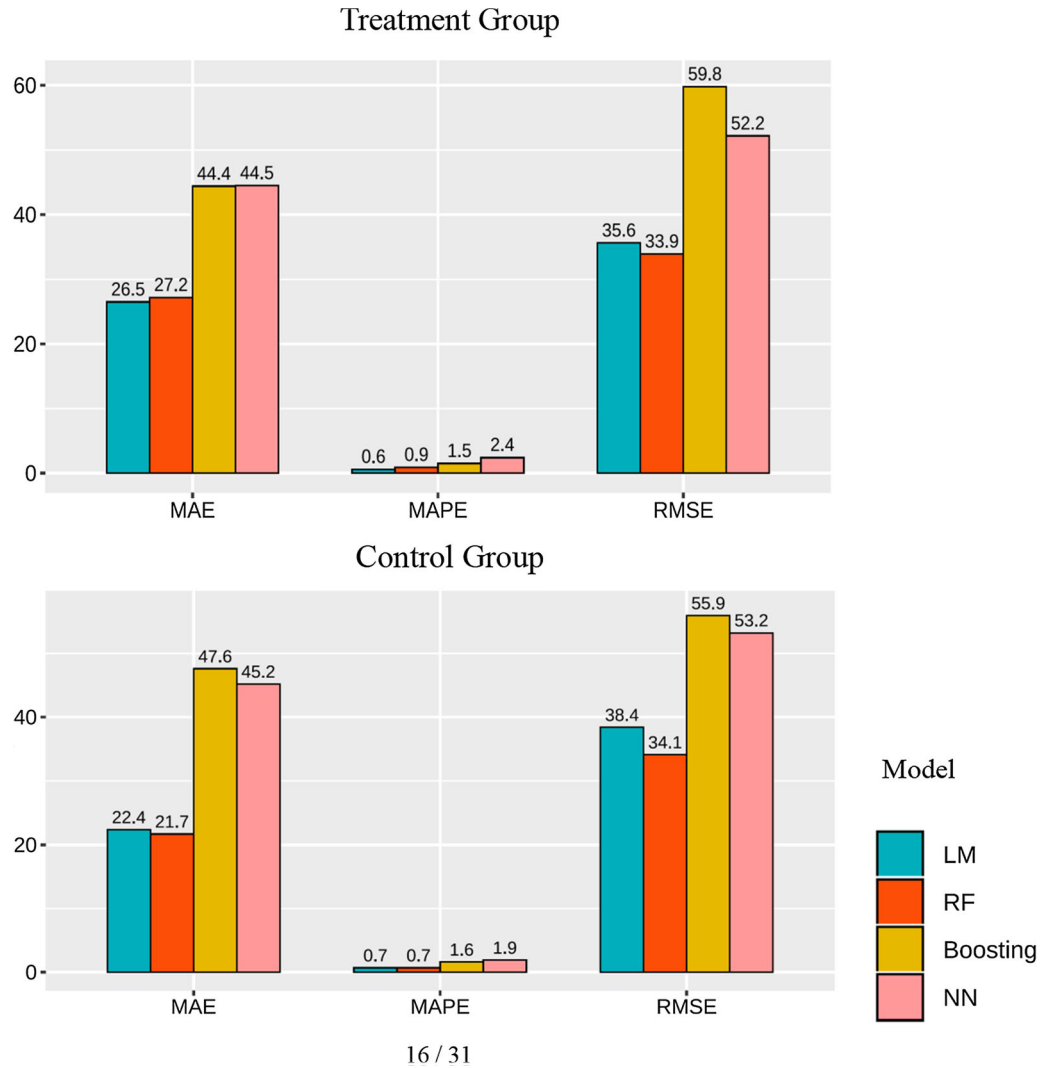


**Fig. 5** The comparision of indexes for model goodness

variables. First, we delete all covariates (eigenvectors) whose samples are less than 100, and replace the missing values of other covariates from the world bank with 0. The number of remaining covariates is 1880, and the number of samples is 1520. We use conflict rank as the dependent variable and all covariates as the explanatory variables to

**Table 2** The list of all penalized covariates

| Covariate with significant coefficient not 0 | Coefficient |
|---|---|
| Total employment rate (percentage) above 15 years old | −9.14 |
| Workforce, female (as a percentage of workforce) | −4.80 |
| Population in the largest cities | −3.73 |
| Carbon dioxide emissions from manufacturing and construction (as a percentage of total fuel combustion) | 2.36 |
| Liner transport related index (2004 max = 100) | −0.64 |
| Coverage of antiretroviral therapy to prevent mother-to-child transmission (percentage of pregnant women living with HIV) | −1.38 |
| Trade in services (as a percentage of GDP) | 2.14 |
| Population in urban agglomerations with a population of more than 1 million (as a percentage of the total population) | −0.77 |
| International tourism revenue (as a percentage of total exports) | 2.36 |
| Net official flows from UN agencies, IAEA (current $) | −0.24 |
| Net official flows from UN agencies, UNAIDS (current $) | −0.53 |

Two decimal places are reserved for the coefficient

conduct Lasso regression. Through tenfold cross-validation and 100 iterations, the results showed that the optimal value of $\lambda$ was 11.533, and there were 11 covariates whose coefficients were significantly different from 0, as follows (Table 2).

In this paper, first, the panel fixed effect is adopted, and the DID approach is taken by setting the intersection of the treatment effect and the time effect. In model (1), the two-way fixed effect of time and national clustering is considered, and the robust standard error is adopted.

In addition, although DID can effectively alleviate the interference and endogeneity problems caused by confounders, the problem of unobservable individual heterogeneity remains difficult to overcome. When evaluating policy, unobservable heterogeneity brings two problems. First, unobservable individual characteristics and the rational expectation of policy consequences are related to the residual in the equation, so that the policy is not a real natural experiment. Second, even if all the observed variables are controlled, the policy implementation on individuals remains heterogeneous. Therefore, in model (2), we further adopt dual machine learning (DML) to address the individual heterogeneity of the treatment effect.

DML uses two lasso methods to simultaneously screen the confounders that affect the outcome variables and the treatment variables, and then it adds them as covariates for causal inference. DML takes the treatment effect as the feature and calculates the difference effect of the experiment by estimating the effect of the feature on the target. Machine learning is good at accurate prediction, and econometrics pays more attention to unbiased estimation. DML combines an econometrics method with machine learning and uses the machine learning models to give an unbiased estimate of the influence of the features on the target [7]. Cross-validation is an important step to ensure the unbiased estimation of DML, and it is used to reduce the estimation bias caused by overfitting (tenfold cross-validation).

**Table 3** Basic DID results

| DV | Conflict | |
|---|---|---|
| Variable | (1) Fe-DID | (2) DML-DID |
| Infrastructure | −10.565*** (−2.954) | −13.558*** (−2.980) |
| Linear term | Y | Y |
| Covariates | Y | Y |
| Time effect | Y | Y |
| Individual effect | Y | Y |
| *N* | 1520 | 1520 |

*T* value in parentheses

*, **, and *** represent significances at 10%, 5%, and 1% levels, respectively

Table 3 shows that *Infrastructure* of models (1) and (2) is significant at the 1% level, and the absolute value is 10.56–13.56, which indicates that the countries along B&R have increased their ranking in their contribution to conflict governance by 10–14 rankings on average. After controlling for the heterogeneity of different countries, the absolute value of the coefficient in the DML-DID (2) is greater than that in DID (1), which shows that their contribution to conflict governance is greater (ranking increased by 28.41%). This proved Hypothesis 1, which states that the relationship between TIC and conflict resolution is justified (Table 3).

Furthermore, considering the randomness of policy intervention time, the time dynamic effect is tested. We set the time nodes 2011, 2012, 2014, 2015 and 2016, multiplied with *B&RCountry* to generate the intersection *Infrastructure2011, Infrastructure2012, Infrastructure2014, Infrastructure2015*, *Infrastructure2016,* and carry out the DID fixed effect. The regression results are as follows:

**Table 4** Fe-DID time dynamic effect

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Infrastructure2011 | −3.631 | | | | |
| | (−1.103) | | | | |
| Infrastructure2012 | | −7.726** | | | |
| | | (−2.355) | | | |
| Infrastructure2014 | | | −11.713*** | | |
| | | | (−3.063) | | |
| Infrastructure2015 | | | | −10.886*** | |
| | | | | (−2.930) | |
| Infrastructure2016 | | | | | −9.592*** |
| | | | | | (−2.701) |
| Linear term | Y | Y | Y | Y | Y |
| Covariates | Y | Y | Y | Y | Y |
| Time effect | Y | Y | Y | Y | Y |
| Individual effect | Y | Y | Y | Y | Y |
| *N* | 1520 | 1520 | 1520 | 1520 | 1520 |

After the policy implementation in 2013, it has a decreasing time dynamic effect (the intersection is significantly negative at the 1% level) in 2014–2016. This may be because, on the one hand the policy was formally introduced into pragmatic promotion in March 2014, which may lead to a lag in policy implications. On the other hand, the infrastructure connection will not achieve overnight effects on the conflict governance, which will take some time to maximize the effect (Table 4).

With the passage of time, the supporting policies for infrastructure construction have been gradually improved along the B&R countries. Although the coefficient of reducing local conflicts has slightly decreased by 18.11% in 2014–2016, it has still remained stable, further indicating the stability of the impact of policies on conflict governance.

### 4.3 Machine learning counterfactual test

The lack of a counterfactual means that the causal effect obtained by the observation method is not equal to the true causal effect. This is the fundamental problem of causal inference rooted in individual differences, wherein the former cannot be regarded as the counterfactual of the latter. The ultimate goal of all analysis tools developed by traditional econometrics, regardless of the adopted research design, is to construct the counterfactual of the treatment group.

In general, these methods assume that after processing, the appropriate control group can be used as the counterfactual of the treatment group, and the difference between them is the treatment effect. This process provides an opportunity to apply machine learning to counterfactual testing: Instead of directly calculating the differences between the treatment group and the control group after intervention, it is better to build a function (such as the weighted average of samples) by using the samples in the control group so that the value of the function after intervention can be regarded as the counterfactual.

In this paper, four machine learning algorithms are used to test the counterfactual: a linear model (LM), the causal random forest (RF), the lifting method (boosting), and a neural network (NN). The reason of choosing these machine learning algorithms is that these methods are most typical in training and predicting data. To construct the counterfactual test, we first randomly take 80% of the samples before 2013 (the implementation of B&R) as the training set and the other 20% as the test set, and we treat the countries' World Bank indicators as the feature set to test the model effect before implementation. The hyperparameters are adjusted by cross validation. Finally, the adjusted optimal hyperparameters and optimal model are tested in the test set, and the out-sample $R^2$ coefficient of the test set is 0.90, indicating that the test effect is good. After 2013, the same procedure was also conducted to test the effect of the model after the implementation. The out-sample $R^2$ coefficient is 0.81, which again shows that the test effect is good.

Next, we use various machine learning algorithms to model the samples before the policy implementation and construct the counterfactual test. Assuming that B&R does not occur, by training for the feature set, we calculate the respective predicted conflict contribution ranking value (counterfactual) and perform a linear regression with the actual value of the policy impact.

For the specific parameters of each model, the boosting algorithm needs to specify the formula, classification dataset, number of iterations, weight update coefficient,

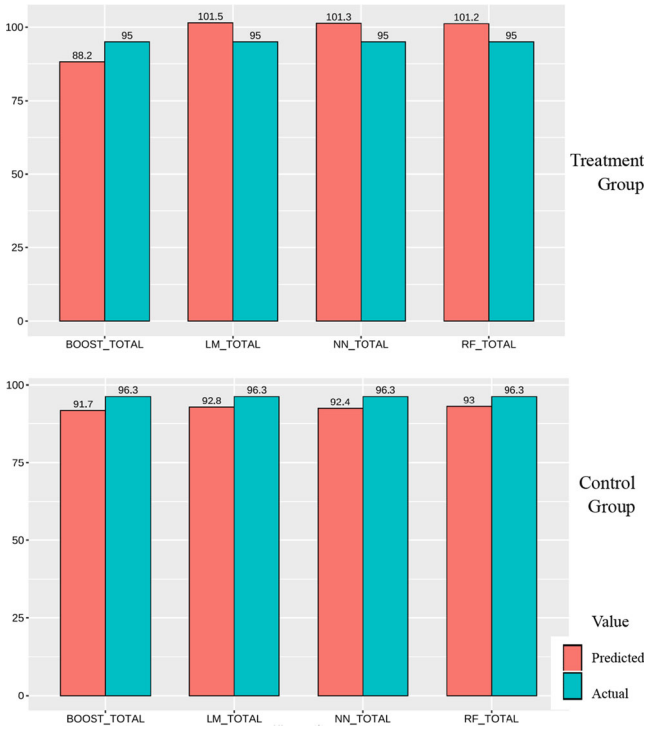


**Fig. 6** Counterfactual test of conflict governance ranking. *Note*: We use the average of countries' conflict rankings in 2013–2017

observation value weight, single decision tree and other parameters for classification. In this paper, the number of iterations is set to 10, the Freund (AdaBoost M1) algorithm is used for the coefficient, and the maximum depth of the observation value weight is set to 3. For the NN algorithm, a back propagation neural network is used. Its output results are propagated forward, and the residual is propagated backward. The number of hidden layer units is set to 3, and the switching linear output unit is selected as the linear output. After the modification of the meta input weight, the weight of the positive parameter decreases (to prevent overfitting), and the maximum weight is set to 10,000.

The $R^2$ coefficient of each model decreases significantly, indicating that B&R indeed has had an important impact on the global conflict contribution ranking.

Regardless of whether countries are along or not along B&R, the mean absolute error (MAE), root mean squared error (RMSE), and mean absolute percentage error (MAPE) of RF and LM are all smaller than the indicators of the previous models. The results show that the LM and RF algorithms have better goodness of fit than the boosting and NN algorithms; this is because boosting is based on a classification tree and better for classification prediction, while the NN is based on an activation function.

Figure 6 shows the results of the counterfactual tests of each model: the actual values from the LM, RF and NN for the countries along B&R are lower than the predicted values (counterfactual, increased by 6–7 rankings, with a change rate of approximately 6.13–6.40%). Compared with the counterfactual, B&R has significantly improved the conflict governance of countries along the B&R, which still supports Hypothesis 1. Only boosting has the opposite effect (the actual value is higher than the predicted counterfactual value), which may be related to the poor fit of the algorithm. Therefore, after considering endogeneity and the other missing variables, even though the rankings of countries along B&R has slightly decreased compared with the DID results, they are still highly significant, proving the robustness of the results.

In contrast, in Fig. 6, the actual values from the LM, RF, NN and boosting in countries not along the B&R are higher than the predicted values (counterfactual, reduced 3–5 rankings, with a change rate of approximately 3.43–4.78%). This finding is consistent with Hypothesis 1.

## 4.4 Subsample analysis

In addition, different countries have different economic development and income levels. As a subsample heterogeneity test, with reference to the World Bank (the criteria being whether per capita GDP is more than 10,000 US dollars), we divide the samples into developed countries and developing countries and carry out subsample regression.

Table 5 shows that relative to developing countries, developed countries have more significant coefficients and larger absolute values for *Infrastructure*, which proved

**Table 5** Regression results between developed and developing countries (I)

| DV | Conflict | | | |
|---|---|---|---|---|
| Variable | Developed countries | | Developing countries | |
| | (1) Fe-DID | (2) DML | (3) Fe-DID | (4) DML |
| Infrastructure | −9.359** (−2.499) | −12.638** (−2.489) | −8.103 (−0.962) | −11.982 (−1.214) |
| Linear term | Y | Y | Y | Y |
| Covariates | Y | Y | Y | Y |
| Time effect | Y | Y | Y | Y |
| Individual effect | Y | Y | Y | Y |
| *N* | 1252 | 1252 | 268 | 268 |

*T* value in parentheses

*, **, and *** represent significances at 10%, 5%, and 1% levels, respectively

Hypothesis 2. The logic behind this finding may be that economic stability and social peace and have greater marginal utility for the development of developed economies, that is to say, the marginal and sunk costs of the economic damage from conflict, violence and terrorism are higher. Therefore, developed countries are more inclined to reduce violent conflict in the region through international cooperation and TIC.

However, there are many shortcomings to measuring developed countries simply by GDP per capita because it is very unstable and it only represents the economic aspect, not the overall development level, of a country. In addition, taking the per capita GDP of US $10,000 as the standard for division, the number of subsamples is not balanced, and there may be sample deviation.

The human development index (HDI) compiled by the United Nations Development Program is thus used to replace the single GDP per capita measurement system and define whether a country belongs among the developed countries. Considering the balance of subsamples, this analysis uses an HDI higher than 0.8 as the standard to divide developed countries and developing countries.

The regression of the subsamples is as follows in Table 6, that shows that even for developed countries (HDI greater than 0.8; only 28.95% of the whole), the coefficient is still significant, and the absolute value is larger than that of developing countries (71.05%). Therefore, there is sufficient reason to believe that Hypothesis 2 is robust (Table 6).

## 4.5 Robustness check

First, China, as the proponent of the B&R, may have a different path than other countries based on its internal mechanism. On the one hand, as a centralized country with multiple ethnic and religious beliefs, China has its own advantages in gathering consensus and reducing conflict. Since ancient times, China has a history of communication, trade and cultural exchanges with foreign countries through the Silk Road and can further deepen and expand on this foundation. Therefore, because China has certain level of endogeneity, the samples of China are eliminated, and the fixed effect and DML are carried out. It is found that *Infrastructure* is still significantly negative at the 1% level, and the absolute value is between 10 and 13.

Second, although the global ranking of violent conflict and terrorism contribution is comprehensive and covers a large set of information, it is also possible that the ranking of other countries will significantly affect the ranking of each country due to the changing trend, which would mean

**Table 6** Regression results between developed and developing countries (II)

| DV | Conflict | | | |
|---|---|---|---|---|
| Variable | Developed countries | | Developing countries | |
| | (1) Fe-DID | (2) DML | (3) Fe-DID | (4) DML |
| Infrastructure | −10.884* (−1.735) | −16.781** (−2.352) | −6.377 (−1.460) | −10.016* (−1.750) |
| Linear term | Y | Y | Y | Y |
| Covariates | Y | Y | Y | Y |
| Time effect | Y | Y | Y | Y |
| Individual effect | Y | Y | Y | Y |
| *N* | 440 | 440 | 1080 | 1080 |

*T* value in parentheses

*, **, and *** represent significances at 10%, 5%, and 1% levels, respectively

that the samples do not meet the mutual independence standard. Therefore, the analysis in this paper further uses the Global Peace Index (GPI, 2011–2017) developed by the Australian Institute for Economics & Peace to describe the level of conflict governance (the missing values in 2010 and the values of missing countries are set to 0).

The measurement of the GPI mainly includes two weights: the degree of domestic peace (accounting for 60%) and the degree of peace in foreign neighboring areas (accounting for 40%), including the degree of social security and militarization. A larger index represents a higher degree of peace. In this paper, the fixed effect DID and DML approaches are still used, and the other settings are consistent with the above.

*Infrastructure* is significantly positive at the 10% level, indicating that the initiative has increased the GPI value of countries along the B&R by 0.07–0.12. Since the average value of the global GPI in 2011–2017 is 1.48 and the standard error is 1.01, a coefficient improvement in this range of 0.07–0.12 is of great economic significance, although the value is small. The relatively smaller significance of the coefficients is related to the smaller fluctuation in the variance in GPI in different countries (1.01) and thus the smaller amount of information.

We may pay more attention to the difference impact of policies based on the sample distribution of different quantiles, that is, the quantile processing effect. Quantile DID measure the heterogeneity treatment effect of pre-quantile for outcome variable. In order to further reduce the estimation error of individual heterogeneity under different covariate distribution, we use quantile DID to study the processing effect of different quantiles. Model (1) does not include all covariates; model (2) adds all covariates and year dummy variables (Table 7).

**Table 7** The results of quantile DID

| Quantile | (1) | (2) |
|---|---|---|
| | Conflict rank | |
| 10 | −12.000* (−1.827) | −8.522* (−1.790) |
| 20 | −10.000 (−1.624) | −8.696** (−2.016) |
| 30 | −16.000 (−1.579) | −7.302 (−1.439) |
| 40 | −20.000** (−2.052) | −14.614** (−2.280) |
| 50 | −13.000 (−1.067) | −13.137* (−1.930) |
| 60 | −18.000* (−1.845) | −14.967*** (−3.300) |
| 70 | −13.000 (−1.427) | −11.978*** (−2.948) |
| 80 | −6.000 (−0.754) | −10.406*** (−2.675) |
| 90 | 3.000 (0.573) | −8.667** (−2.147) |
| Linear term | Y | Y |
| Covariates | N | Y |
| Time effect | N | Y |
| *N* | 1520 | 1520 |

The results show the policy contribution to conflict governance in different quantile countries shows an inverted "U" effect with small at both ends and large in the middle. In the middle quantile countries (the middle of the global conflict governance ranking), policy implementation has the greatest effect on conflict governance. For countries with lower and higher quantiles, the coefficient of policy impact is relatively small.

## 5 Mechanism

The next challenge is identifying the path through which TIC affect the governance level of local conflicts. In the theoretical analysis, this paper argues that TIC may have a substantial impact on global conflict governance through different mechanisms. In the model design, we put the adjustment variables in the benchmark model to investigate whether the influence mechanism is significant. The specific model design is as follows:

$$\begin{aligned}\text{Conflict}_{it} = {} & \theta_1(\text{Moderator}_{it} \times \text{Infrastructure}_{it}) \\ & + \theta_2 \text{Infrastructure}_{it} + \theta_3 \text{Moderator}_{it} \\ & + \beta X_{it} + \text{year}_t + v_i + \mu_{it}\end{aligned} \tag{2}$$

TIC is based on respecting the sovereignty and security of the relevant countries and on the joint efforts of all countries to create composite infrastructure networks through railways, highways, shipping, aviation, pipelines, and spatially integrated information networks. The transaction costs of commodities, funds, information, and technology among regions have been greatly reduced by the B&R, which has effectively promoted the orderly flow and optimal allocation of cross-regional resource elements and achieved mutually beneficial cooperation and win–win development. We think that TIC can influence conflict resolution through three channels: trade facilitation, equal employment across gender, and income growth.

### 5.1 Trade facilitation

TIC may also promote trade liberalization and facilitation, reduce business costs, release development potential, and further enhance the breadth and depth of participation in the economic globalization of different countries. Therefore, we further select the net goods and services trade (BOP, current price USD), goods trade (percentage of GDP), logistics performance index (quality of trade and transport-related infrastructure) and manufacturing exports (percentage of goods exported) from the World Bank to generate the intersections and construct a fixed effect model.

Table 8 shows that *Net goods and services trade, Goods trade, Logistics performance index* and *Manufacturing*

**Table 8** Mediating effect of trade facilitation

| DV | Conflict | | | |
|---|---|---|---|---|
| Variable | (1) | (2) | (3) | (4) |
| Net goods and services trade × Infrastructure | −3.768** (−2.261) | | | |
| Goods trade × Infrastructure | | −0.220*** (−4.887) | | |
| Logistics performance index × Infrastructure | | | −2.405** (−1.979) | |
| Manufacturing exports × Infrastructure | | | | −0.190*** (−3.173) |
| Quadratic intersection | Y | Y | Y | Y |
| Linear term | Y | Y | Y | Y |
| Covariates | Y | Y | Y | Y |
| Time effect | Y | Y | Y | Y |
| Individual effect | Y | Y | Y | Y |
| *N* | 453 | 1520 | 1520 | 1520 |

*T* value in parentheses

*, **, and *** represent significances at 10%, 5%, and 1% levels, respectively

*exports* are significantly negative in all mediations of Infrastructure connectivity, which proves Hypothesis 3.

## 5.2 More equal employment across gender

TIC is likely to reduce the frequency of conflicts by increasing local employment opportunities and improving the work-leisure time ratio of residents. However, affected by the differences in cultures and customs, the participation of different genders in the labor force may have different paths for the impact of infrastructure construction on global conflicts. To test the impact of employment by gender, we chose the labor participation rate, the number of unemployed, and the industrial employment of the different genders from the World Bank.

Table 9 are shown all fixed effects models: from the perspective of the adjustment variables for the proportion of employment of different genders, the higher the female

**Table 9** Mediation of employment on infrastructure for conflict resolution

| DV | Conflict | | | | | |
|---|---|---|---|---|---|---|
| Variable | (1) | (2) | (3) | (4) | (5) | (6) |
| Female participation × Infrastructure | −0.504*** (−3.636) | | | | | |
| Male participation × Infrastructure | | −0.191 (−0.532) | | | | |
| Female unemployment × Infrastructure | | | 0.558* (1.742) | | | |
| Male unemployment × Infrastructure | | | | −0.403 (−0.970) | | |
| Female industry × Infrastructure | | | | | −1.092*** (−3.686) | |
| Male industry × Infrastructure | | | | | | −0.502** (−2.372) |
| Quadratic intersection | Y | Y | Y | Y | Y | Y |
| Linear term | Y | Y | Y | Y | Y | Y |
| Covariates | Y | Y | Y | Y | Y | Y |
| Time effect | Y | Y | Y | Y | Y | Y |
| Individual effect | Y | Y | Y | Y | Y | Y |
| *N* | 1520 | 1520 | 1520 | 1520 | 1520 | 1520 |

*T* value in parentheses

*, **, and *** represent significances at 10%, 5%, and 1% levels, respectively

labor participation rate is, the lower the proportion of female unemployment and the better the conflict resolution will be, which proved Hypothesis 4. When there are more job opportunities brought by TIC, women choose to go out of the home and enter the labor market, improve the participation rate of the female labor force and reduce the number of unemployed females [33, 36]. Thus, women's unique flexibility can be brought into play to mitigate violent conflicts.

The coefficient of industrial employment for men and women further proves our hypothesis. Through infrastructure construction, increased employment is more reflected in industrial employment. Both the male and female industrial employment coefficients are significantly negative, which shows that industrial employment can reduce violent conflict through TIC. The absolute value of the female coefficient is approximately twice that of the male coefficient, which further proves that the increase in female employment has a greater spillover effect on the proportion of work-leisure time and a greater promotion effect on social stability.

### 5.3 Income growth

Infrastructure construction is likely to improve the income level and quality of life of local residents and thereby reduce their motivation and to participate in violent conflict and its appeal. We choose GDP per capita (logarithm of constant price USD in 2010), adjusted national net per capita income (logarithm of constant price USD in 2010) and total savings (percentage of GDP) as adjustment variables to generate the intersection with *Infrastructure* and build a fixed effect model.

Table 10 shows that the adjustment effect coefficients of per capita GDP, per capita income and total savings are significantly negative, which proves Hypothesis 5. In addition, some scholars [45] have suggested that total social savings could also be used as an indicator of social stability because an increase in total social savings can improve people's expectations for their future quality of life and, as a social asset, total social savings is also the embodiment of social trust and social risk avoidance. Therefore, total social savings can play a stabilizing role in reducing violent conflict, consistent with the existing literature.

## 6 Conclusion and discussion

This paper presents new evidence of the effects of TIC on conflict resolution. It is widely assumed in other studies that TIC has an unclear effect on local conflict resolution: TIC could even facilitate the transportation and spread of local rebellion forces to aggregate military weapons [8]. In contrast, this paper presents the downside by conducting a natural experiment and applying machine learning methods to overcome the endogeneity issue, as follows.

First, TIC can significantly improve countries' status in the global ranking of conflict resolution by an average of 6–13 positions, which proved Hypothesis 1 and underlines the alleviation of conflict severity and the improvement of conflict governance. Through several robustness checks, such as eliminating the Chinese endogenous sample, substituting DV with GPI, and eliminating other policies, we found that the main results are still robust.

The practical implication of Hypothesis 1 is that the success of conflict resolution should depend more on the participation and cooperation of neighboring countries, especially in TIC. This should include any attempt to advance the bilateral improvement and convenience regarding transaction and transportation costs and barriers. The participation of other neighboring countries in transborder transportation could boost the ability to establish the sound order that would give each country free rein in regional peace and stability [47]. More broadly, transportation connectivity is also linking potential markets

**Table 10** Mediation of income on infrastructure for conflict resolution

| DV | Conflict | | |
|---|---|---|---|
| Variable | (1) | (2) | (3) |
| GDP per capita × Infrastructure | −4.747*** (−2.758) | | |
| Income per capita × Infrastructure | | −3.666* (−1.775) | |
| Total saving × Infrastructure | | | −0.358** (−2.455) |
| Quadratic intersection | Y | Y | Y |
| Linear term | Y | Y | Y |
| Covariates | Y | Y | Y |
| Time effect | Y | Y | Y |
| Individual effect | Y | Y | Y |
| *N* | 1467 | 1160 | 1520 |

among developed and developing countries, which would prove particular advantages for each side if the supply chains are created to benefit the global consumer–producer network [19].

Second, we take distance from Kirkpatrick et al. [24], who affirm that developed countries are more susceptible to the effect of the transport infrastructure in a conflict because the provision of efficient, reliable, and affordable infrastructure services for developing countries is an essential requirement for economic growth and sustainable development. In contrast, we prove that the marginal benefit of TIC on conflict is greater for developed countries than for developing countries. Thus, Hypothesis 2 is also verified.

On average, the marginal effect for developed countries is 39.79% superior (approximately 1–5 ranking positions) that of developing countries. In addition, through the Quantile DID, we also find that countries in the middle of the conflict rank are more vulnerable to the impact of TIC on conflict governance, similar to an inverse U-shape.

The practical implication of Hypothesis 2 is that investing in large-scale inter-regional infrastructure projects can be a highly profitable business for developed countries from both a political and economic perspective, especially if the conflict tendency is in its seed stage. In effect, transport infrastructure investments, such as the trans-European transport (TEN-T) network, often generate welfare effects at the regional level that contribute to the cohesion objective on a community scale [6]. In addition, cross-border infrastructure investments in developed countries highlight the need for the smooth coordination of various actors, the top-level backing of projects, and an understanding of all of the political and financial factors that influence the success of such projects [16, 31].

In contrast, given that many undeveloped countries do not present prosperous economies, it is crucial to ascertain their capability to repay the TCI bank loans. Indeed, these countries may "throw the helve after the hatchet," especially considering the risky involvement of private investments [37]: transport infrastructure investments still have risks related to achieving conflict resolution, especially those with a high degree of privatization [23]. Even though policy-making implications are not completely evident, our paper addresses the need to reconsider the criteria of investor selections involving private participation, which have been biased toward large international operators [41]: in particular, developing countries' investors should be vigilant against infrastructure projects with private participation.

Third, we found that the mechanisms behind the effect of TIC are the mediating role of trade facilitation (Hypothesis 3), equal employment between genders (Hypotheses 4), and income growth (Hypothesis 5), which further support conflict resolution.

The practical implications of Hypothesis 3–5 are that (1) given the complex, two-way interactions between trade facilitation and existing transnational conflicts, the distinction between "source" and "target" countries of conflict should be separated and the intertemporal persistence of conflict should be taken into account to balance the sustainability of TIC [32], (2) because women are significantly more active in domestic than international terrorist organizations [18] and earn lower salaries than men, improving their social status and providing them with more decent occupations are necessary to motivate them to raise from their actual status,and (3) given that the rise in fundamentalist terrorism has mainly impacted the Middle East and Asia—with the largest Islamic populations [17]—the income level and living standards among citizens should be the first priority to act as a ''peace dividend'' against conflict and terrorism.

Overall, although the motives of conflict may differ, the homogenizing effect of trade facilitation, equal occupation between genders, and income increases provided by TIC play a fundamental role in the splitting effect of TIC on conflict resolution. However, in this regard, also to be highlighted is the importance of personalized security policies at the local level that may differ according to peculiar regional situations aimed at obtaining peace and stability: in some cases, advanced economies could help undeveloped neighboring countries alleviate their conflict externalities through trans-border connections; however, in other situations, doing so may not work and may even have the opposite effect for war-torn countries.

Although our contribution to TIC studies is innovative, it recalls the past research of Ali et al. [2] on the relationship between infrastructure and conflict and who demonstrated that reducing transport costs benefits welfare. However, when an intense conflict occurs, improvements in infrastructure may not have the expected benefits: because conflicts arise when there is a mismatch between people's perception concerning happiness on the one hand and development and damage on the other [28], policy makers and decision makers should focus on resolving basic infrastructure issues to optimize their chance of facilitating production and quality of life.

Generally, however, investments that decrease transportation costs are highly effective for conflict resolution, especially through transnational cooperation. While it is not clear how future global and regional conflicts will evolve, this study has shown that facilitating TIC is an important tool to catalyze economic growth and end the perpetual conflict trap. In particular, we emphasize that the results do not call for an unqualified encouragement of TIC in all conflict-prone areas. However, the analysis suggests

being aware of the unwanted consequences and the opportunity to combine these investments with greater security to realize economic and social benefits.

The limitation of this paper is that the real world may not work as the machine learning predicted because random contingency, subjective preference, and individual independence; however, this paper reports on exploratory research that gives rise to further in-depth studies. First, deeper case studies in typical regions may be useful for big data empirical studies. Second, the distinction between internal and cross-border infrastructure connectivity could also be highlighted in future research. Third, the heterogeneity test of different transportation means, such as roads, ports, and railways, in conflict resolution is also worth deepening. Finally, this study could be a starting point for exploring the vulnerability of the transport infrastructure to conflicts and their degree of correlation.

## Declarations

**Conflict of interest** The authors declare that they have no competing interests.

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