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A gravity model for international trade and conflict

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Abstract. This paper investigates the nexus between conflict and trade using data from 77 countries. For this purpose, it puts forward a gravity model that is augmented with interstate conflict casualties. In order to overcome statistical problems related to heteroscedasticity and the omission of the extensive margin (the zero observations), the gravity model is estimated using a Poisson Pseudo-Maximum Likelihood method (PPML). The model suggests a downward impact on trade that affects all sides of the conflict, whether they suffer casualties or deal them. However, said impact remains small, which hints that even before direct conflicts occur, the involved countries are less likely to have significant trade flows.
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1. Introduction

From 1946 to 2017, the number of active armed conflicts jumped from 16 to over 50. In 1989, these conflicts –whether state-based or non-state, were 39 in total (Dupuy & Rustad, 2017). Simultaneously, the amount dedicated to military spending worldwide has been constantly increasing and its proportion has been kept significantly high within most government budgets[1].

In light of these trends, armed conflict is an *undisputable* part of modern reality that determines a plethora of social, political and economic variables. In this context, the present paper examines the nexus between conflict and trade, and motivates for that end a gravity model that incorporates battle-related deaths.

In section II, I present the gravity model that encompasses armed conflict casualties. Emphasis shifts in section III towards the data, and the selection of the examined countries according to their income level. In section IV, the model's results are discussed, and section V concludes.

2. The model

I use an augmented gravity model that includes bilateral conflict-related deaths, in order to evaluate whether the latter affects trade flows, and by extension GDP per capita. This approach takes underpinning in the

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[1] From 1988 to 2018, the world military expenditure went from 1.5 to 1.82 trillion USD in constant terms (Stockholm International Peace Research Institute, 2018)

assumption that the main channel through which conflict deaths could affect GDP, would be through trade. War casualties –no matter how few they could be, are a signal of tension between at least the directly involved countries. If said tensions are translated into trade restrictions, this could affect GDP, as the foreign component of the aggregate demand would be affected. In addition, trade flows could simply tumble amidst mere security risks related to the existence of a deadly conflict.

The outcome of the gravity model estimation should also provide hints on whether or not there is an impact on investment, since trade goes hand in hand with foreign direct investments (FDI) according to an overwhelming number of empirical studies (e.g. Büthe & Milner, 2008; Fukao *et al*. 2003). In this study, however, the focus is not put on investment as a dependent variable.

Initially, gravity models are inspired from Isaac Newton's Law of Gravitation. Their canonical form can be expressed as follows:

$$X_{ij} = G.\frac{Y_i^{\zeta 1}.Y_j^{\zeta 2}}{d_{ij}^{\zeta 3}}.\omega_{ij} \tag{1}$$

Where X_{ij} is the exports movement from country of origin i to country of destination j. Y_i and Y_j respectively represent the mass of the two economies, measured by GDP. d_{ij} accounts for the distance between each pair of origin-destination countries. G is a gravitational constant, which is supposed to account for other potential factors in this canonical version of gravity models. As for ω_{ij}, it is the error term, which is assumed to be log-normally distributed.

In case of log-linearization, Equation (1) becomes:

$$LogX_{ij} = \zeta_0 + \zeta_1.Log(Y_i) + \zeta_2.Log(Y_j) + \zeta_3.Log(d_{ij}) + \varepsilon_{ij} \tag{2}$$

With: $\zeta_0 = Log(G)$; $\varepsilon_{ij} = Log(\omega_{ij})$; $\zeta_3 \leq 0$

In the present research, I estimate a dynamic version of this model (including time t) that is augmented with the number of conflict-related deaths. I also add a number of control variables Ω_{ij} based on various extensions of the model in the literature (*e.g.* Rose, 2000):

$$LogX_{ijt} = \zeta_0 + \zeta_1.Log(Y_{it}) + \zeta_2.Log(Y_{jt}) + \zeta_3.Log(d_{ij}) + \alpha.Log(Z_{ijt}) + \beta.\Omega_{ij} + \varepsilon_{ij} \tag{3}$$

Here, Z_{ijt} is the number of (interstate) battle-related casualties. The controls Ω_{ij} include variables that are related to (i) cultural and geographic proximity, via dummy variables for contiguity, common colonisers, post-1945 colonial relationship, common religion, and common (official) language. The controls also encompass (ii) dummy variables related to free trade agreements, common currency and GATT/WTO membership.

It is worth emphasising that in the potential presence of heteroscedasticity in the gravity model, the nonlinear transformation (*e.g.* via logarithm) of the variables expressed in equations (2) or (3) would most likely generate unreliable results. This econometric problem was first pointed out by Santos-Silva & Tenreyro (2006) who argue that a heteroscedastic error term in gravity models (ω_{ij} in this case) leads to a linear correlation between its logarithmic form (ε_{ij}) and the covariates, which would lead to inconsistent estimates of the coefficients (Santos-Silva & Tenreyro, 2006). Even in other non-gravity models, it is only when there is no linear relationship between the two that an OLS estimation of the log-linearized equation can generate the best possible linear approximation (Goldberger, 1991).

Log-linearization is also blameable for another significant statistical problem in gravity modelling, *i.e.* the exclusion of the zero observations, thereby failing to capture for example the extensive margin of trade (Liu, 2009). And like in the present paper, this issue is more probable when small countries are considered (Santos-Silva & Tenreyro, 2006). It is even more severe when considering that the number of bilateral conflict-related casualties is zero in most cases, and non-zero numbers of deaths are usually registered only during a short period of one to three year, *e.g.* the early 1990s Gulf War and several very brief skirmishes between some Sub-Saharan African countries. Thus, the elimination of zero-casualties pairs and zero-trade pairs would lead to the loss of much of the model's expected explanatory power.

In order to avoid these problems, I opt for the Poisson pseudo-maximum likelihood (PPML) approach with fixed effects, which is robust and properly addresses heteroscedasticity. The PPML also effectively handles zeros without any truncation of the panel, as it solves the model multiplicatively without any nonlinear transformation. Ergo, it even allows interpreting the coefficients as elasticity when combining variables in levels and in logarithms.

3. The data

In order to estimate the gravity model, I use data from 77 countries on a bilateral basis. I cover countries from different regions and income groups. The different classifications are based on the most recent update by the World Bank Group. The different countries and their income groups are listed in Table 1.

The data is for the period between 1989 and 2014. I exclude the short period between 2014 and 2019 because of missing bilateral data for several country-pairs, which would have generated an unbalanced panel. I use data based on the CEPII square gravity model, while the bilateral trade flows are collected from the UN COMTRADE[2]. The number of bilateral battle-related deaths are taken from the Uppsala Conflict Data Programme.

In this framework, it is worth observing that the gravity model is confined to *interstate* battle-related casualties, because even though there is a few deadly civil wars/insurgencies that were *allegedly* supported by foreign countries, it is not possible to establish the direct link to the supporting countries in most cases. Hence, for the sake of research objectivity, I chose to consider only the casualties that happened in conflicts directly or officially involving the states of the 77 countries I study. The variable includes the number of casualties among civilians and military/paramilitary forces, whether the origin country suffered said casualties or dealt them to the other side of the conflict (country of destination of the trade flow).

Table 1. *List of the examined countries*

LIC [Low-income]	LMC [Lower-mid income]	UMC [Upper-mid income]	HIC [High-income]	
Burkina Faso	Angola	Algeria	Argentina	Ireland
Chad	Bangladesh	Armenia	Australia	Israel
Eritrea	Cambodia	Botswana	Austria	Italy
Ethiopia	Cameroon	Bulgaria	Bahrain	Japan
Liberia	Egypt	Colombia	Belgium	Kuwait
Malawi	Ghana	Guatemala	Canada	Lithuania
Mali	Indonesia	Iran	Chile	Panama
Mozambique	Kenya	Iraq	Croatia	Saudi Arabia
Niger	Mauritania	Jordan	Cyprus	Singapore
Rwanda	Morocco	Lebanon	Czech Republic	Spain
Senegal	Nicaragua	Malaysia	Denmark	Switzerland
Sierra Leone	Nigeria	Mexico	Finland	UAE
Syria	Pakistan	Namibia	France	United Kingdom
Yemen, Rep.	Sudan	Peru	Germany	United States
Zimbabwe	Ukraine	Russian Federation	Hungary	Uruguay
		South Africa		
		Turkey		

4. Emprical results

The gravity model estimates are reported in Table 2, with four different variations. For all four, I use the Poisson pseudo-maximum likelihood pursuant to the discussion above. Since the model covers all possible combination among the 77 countries, the number of observations used in the regression is quite considerable, *i.e.* 143,354 observations.

In column 1 of the table, I estimate the correlation between interstate battle-related casualties and trade flows in a canonical gravity model that includes respective gross domestic products (size of the economies) and the weighted distance between countries in each pair. The results suggest a very weak negative coefficient of correlation of -0.00009, which is

[2] The different dummy variables used were constructed by CEPII based on the World Trade Organisation information, Baier & Bergstrand (2007), Frankel (1997) and Glick & Rose (2002).

statistically significant at the 10% threshold. The coefficient becomes slightly more significant in column 2 (-0.00016 at 5%) where dummy variables are introduced to control for a number of bilateral cultural and geographical aspects, such as the existence of a colonial relationship, a common coloniser (post-1945 period), a common religion, a common official language or contiguity. However, the deaths coefficient shows no significant impact when including currency and trade dummy variables instead (column 3), *i.e.* common currency, regional/free trade agreements, GATT/WTO membership among the countries of origin and destination of the trade flow.

In column 4, where all the factors controlled for by dummy variables are included, the relationship between battle-related deaths and exports retrieves its statistically significant negative sign, yet with a small coefficient of -0.00014.

On the other hand, it is worth observing that the main variables of the gravity model (distance and GDPs) show a robust stance that is strongly consistent with theory. As regards to the dummy variables, it is possible to observe that countries are less likely to trade with those with which they shared the same coloniser (largely negative coefficient of correlation between -1.48 and -1.57), but more likely to trade with their former coloniser (0.234; 0.512). Having the same official language is not a binding condition; it is the only factor that holds no significant effect on trade. Having a common religion seems to drive a negative effect on trade in the panel, while the rest of the dummy variables show patterns that follow economic intuition. Like the distance and GDPs, all the dummy variables maintain similar coefficients with large statistical significance regardless of the model's specification, hence the robustness of the cultural, geographical and trade-related factors in determining trade flows dynamics.

To sum up, the gravity model estimates suggest that in most cases the existence of bilateral conflict casualties could affect trade flows between pairs of countries in a downward course, however in a very marginal proportion. This means that there is a risk that battle-related deaths could affect GDP per capita if I consider the overwhelming literature on the latter's positive relationship with trade. This outcome also insinuates a negative influence on investment, following the arguments explained above and largely backed up by empirical studies (e.g. Büthe & Milner, 2008; Fukao *et al*., 2003).

Most importantly, the model suggests that this negative impact driven by battle-related deaths happens for both sides of the conflict, whether they suffer casualties or deal them. This could be interpreted as conflict driving a net downward influence on global trade and GDP, *ceteris paribus*. Nevertheless, the negative influence of conflict observed in three out of four model versions remains quite small –and one version refutes the existence of such influence. This could suggest that before a direct clash even occurs, the involved parties tend not to have significant trade flows as a repercussion of different potential factors, such as political tensions;

hence, the losses in trade might be only partially explained by armed conflict.

Table 2. *PPML estimation of the gravity model with battle-related deaths [Dependent variable: X_{ijt}]*

VARIABLES	(1) Baseline	(2) Cultural DV	(3) Trade DV	(4) All
Battle-related casualties Z_{ijt}	-0.000092*	-0.000161**	-0.000018	-0.000141***
	(5.04e-05)	(6.83e-05)	(3.79e-05)	(3.01e-05)
Weighted distance d_{ij}	-0.000311***	-0.000176***	-0.000160***	-0.0000938***
	(7.12e-06)	(6.09e-06)	(5.08e-06)	(4.52e-06)
GDP of exporter Y_{it}	3.19e-13***	2.73e-13***	2.75e-13***	2.45e-13***
	(3.26e-15)	(3.71e-15)	(3.94e-15)	(3.47e-15)
GDP of importer Y_{jt}	3.34e-13***	2.89e-13***	2.90e-13***	2.61e-13***
	(3.44e-15)	(3.80e-15)	(4.25e-15)	(3.70e-15)
Colonial relationship		0.234***		0.512***
		(0.0415)		(0.0406)
Common colonizer (post 1945)		-1.485***		-1.573***
		(0.0868)		(0.0802)
Common religion		-0.120**		-0.546***
		(0.0483)		(0.0457)
Common official or primary language		-0.0549		-0.0490
		(0.0449)		(0.0353)
Contiguity		1.843***		1.472***
		(0.0486)		(0.0460)
Common currency			0.972***	1.100***
			(0.0738)	(0.0499)
RTA			1.294***	1.095***
			(0.0338)	(0.0325)
Exporter is GATT/WTO member			0.853***	0.833***
			(0.0435)	(0.0423)
Importer is GATT/WTO member			1.169***	1.152***
			(0.0402)	(0.0386)
Constant	20.74***	20.08***	17.81***	17.64***
	(0.0320)	(0.0368)	(0.0592)	(0.0582)
Observations	143,354	143,354	143,354	143,354

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

5. Conclusion

This research examines the relationship between conflict and trade in 77 countries, using an augmented gravity model that encompasses battle-related deaths. To generated robust outputs and avoid an omission bias due to the zero observations for both trade and deaths, the model is estimated using a Poisson Pseudo-Maximum Likelihood method (PPML). As expected, the results suggest a negative impact of conflict in most of the model's versions. This downward influence takes places regardless of which side of the conflict suffered the casualties. Nonetheless, the small size of the conflict coefficient could mean either that a part of the bilateral trade remains despite armed conflicts, or that only country-pairs with already decreasing trade flows are likely to select into armed fighting. Future research should verify the robustness of this interpretation.

Like any study examining complex multidimensional phenomena such as the war-economy nexus, this study has several limits, including the possibility of endogeneity. One cannot deny that a large number of the deadly conflicts that have taken place since 1989 occurred *geographically* in LDCs, which could suggest the existence of confounding factors related to the country's level of development.

Furthermore, when considering the conflict theatre (location) in modern warfare, it is possible to argue for other factors influencing trade and GDP per capita. Such factors could include the deterioration of infrastructure due to airstrikes, the high political and economic instability or the drastic movements of the population and their direct impact on production. Sending troops or sponsoring militia in a different country certainly does not have the same economic impact as being on the receiving end. These factors are at least as much influent and plausible as the variables presented in this paper, hence the risk of endogeneity. Future research work should also shed light on this particular matter.

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