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The Economic Costs of Hybrid Wars: The Case of Ukraine

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ABSTRACT

With more than ten thousand casualties, the ongoing hybrid Ukrainian war between pro-Russian separatists and the government in the Donbass region, Ukraine's productive core, has taken a severe toll on the country. Using cross-country panel data over the period 1995–2017, this paper estimates the causal effects of the Donbass war on Ukraine's GDP. Our counterfactual estimation by the synthetic control method shows that Ukraine's per capita GDP foregone due to the war amounts to 15.1% on average for 2013–2017. Separate analysis for the affected regions of Donetsk and Luhansk indicates an average causal effect of 47% for 2013–2016. Results are robust to pre-war confounds, namely, the Orange Revolution and Ukrainian-Russian gas disputes. As such, we discuss mechanisms underlying the war's causal effects on economic performance, which is of broader relevance for debates on the role of government in hybrid conflict management.

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Introduction

The effectiveness of hybrid warfare, described as the use of insurgent tactics coupled with conventional military power to achieve politico-strategic goals, relies on ethnic grievances and weak civil societies (Lanoszka 2016). Due to the close link between belligerents and the target society as well as the evolving and unpredictable nature of such conflicts, governments face several challenges in developing conflict management strategies (Giegerich 2016). For instance, counter-insurgencies may deteriorate rather than improve the country's state of affairs.

Military conflicts always entail large costs, including economic, social, political, psychological and environmental ones. A vast literature is devoted to the ex-post evaluation of the economic costs of conflict to assess the losses incurred by the states and the civil society. Starting from Keynes (1919), many studies show that war has persistent negative consequences on the welfare of the populations involved (see, e.g. Gates 2012; Koubi 2005; Abadie and Gardeazabal 2003). To our knowledge, this is the first paper that identifies and quantifies the causal effects of the hybrid war in the Donbass region on Ukraine's GDP. Additionally, our study discusses mechanisms underlying these causal effects, and statistical challenges in the analysis arising from the complex nature of hybrid wars.

The War

The Donbass war is an armed conflict between anti-government groups of pro-Russian separatists and the Ukrainian government, taking place in the aftermath of the 2013 Euromaidan protests and the 2014 Ukrainian revolution. Thereby, this war embodies the hybrid form of state-on-state

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(Russian-Ukrainian) conflict. Located in eastern Ukraine, the Donbass region is considered Ukraine's productive core due to coal mining and highly productive heavy industry.¹ As such, the Donbass war has taken a severe toll on Ukraine, especially in terms of production, employment, number of displaced persons, and civilian as well as military casualties (Angelovski 2015).

The Donbass is of considerable importance for Ukraine's production. Before the 2014 Ukrainian Revolution, this region accounted for about a quarter of the country's exports and more than 15% of capital investment (Ukrstat 2014). For instance, the Donbass used to provide raw materials such as coal, steel and other industrial goods to international manufacturing industries. As of August 2014, the industrial production dropped by 60% and 85% in the Donbass regions of Donetsk and Luhansk, respectively, due to power cuts and the destruction of transport infrastructures (Havlik 2014). Overall, major reasons for the decline of Ukraine's economic activity are high costs of trade together with employment, agricultural and financial losses, compressed government spending, and the partial military mobilization coupled with growing political instability (Foreign Affairs Ministry 2015).

As a *hybrid* and complex form of warfare, the Donbass war is an especially interesting case study.² Modern conflicts are indeed more likely to arise as a consequence of regional struggles with governments facing non-governmental actors who operate in concert with external players. Specifically, hybrid wars especially threaten the government's sovereignty due to lack of soil governance and means to tackle issues like unclear front lines or friendly/enemy areas; unclear *casus belli* and politico-strategic goals; and new tactics that focus on the weakening of governments and state institutions rather than on direct combat (Deshpande 2018).

In this respect, this paper aims to help deconstructing the complexity of the Ukrainian conflict by (i) providing formal statistical evidence on the causal effects on the country's economy both at national and regional levels and (ii) discussing market mechanisms underlying these effects, also in the prospects of governments' conflict management and resolution.

The War's Outcomes

Due to the Donbass' strategic role in the country's economy and its large contribution to the GDP, we expect the war to have a negative *causal* impact on this outcome. Although its components are of relative importance in determining the causal effect, we focus on the GDP foregone as an aggregate measure of the economic costs for two reasons. First, we want to allow for a higher degree of internal and external validity of our analysis. This approach is also followed by, e.g. Costalli, Moretti, and Pischedda (2017), Horiuchi and Mayerson (2015), and Abadie and Gardeazabal (2003), who find strong significant average per capita GDP losses ranging from 8.6% to 17.5% (see, e.g. Gardeazabal 2012, for a review of existing studies). As such, constructing an accurate (in terms of quality of the available data) and reliable (in terms of theoretical guarantees) counterfactual for Ukraine's per capita GDP contributes to the cross-country comparison of our results with the literature. Second, since the Donbass war is still ongoing at the time of writing, it is difficult to give precise estimates of other types of costs due to lack of data. In light of these factors, we consider per capita GDP foregone as the main measure of welfare loss.

Empirical Strategy

We use the Synthetic Control Method (SCM) to estimate causal effects of this war on Ukraine's GDP per capita. Since its first application by Abadie and Gardeazabal (2003) and later formalisation in Abadie, Diamond, and Hainmueller (2010), this method has been more recently employed to estimate the causal effects of conflicts on GDP by, e.g. Echevarría and García-Enríquez (2019a, 2019b) but also by, e.g. Albalade and Bel (2020) to estimate the effects of government formation deadlocks on GDP growth.

Building on the potential outcome approach (Rubin 1974), we obtain the counterfactual, 'synthetic', Ukraine as a weighted average of control (unaffected) countries with weights reflecting the resemblance of both the outcome variable and outcome predictors in Ukraine before the war's outbreak.

A country-level panel data over the period 1995–2017 are used for the analysis. Causal effects are estimated by computing the yearly difference in GDP per capita between Ukraine and its synthetic counterpart after the eruption of the war. Moreover, we apply the SCM iteratively to check for other potential shocks taking place in Ukraine before the Donbass war, in particular, the 2004 Orange Revolution, and the 2009 gas dispute with Russia. Finally, since the war is likely to affect the Ukrainian territory unequally, we further conduct a similar analysis for the Donbass regions of Donetsk and Luhansk.

Preview of Results

Results indicate that due to the Donbass war, whose start is set to 2013, Ukraine's foregone GDP per capita amounts to 15.1% on average in the post-war period and, respectively, 5.23% (\$460.26), 9.18% (\$832.96), 19.63% (\$1,823.78), 19.80% (\$1,893.38), 21.67% (\$2,184.13) in 2013, 2014, 2015, 2016, and 2017. The obtained estimates are validated by a series of robustness checks. After iteratively applying the SCM, we find that gas disputes led to an overestimation of the previous causal effects by 1.21 percentage points (\$128.04) on average. Instead, our findings show that the Orange Revolution did not considerably influence Ukraine's economic development and, thus, did not confound the obtained causal estimates of the war. Lastly, results from the regional analysis confirm the devastating effect of the war for the Donbass area. In particular, we estimate that Donetsk's per capita Gross Regional Product (GRP) dropped by 42% (\$4,294) on average due to the war. Estimates for Luhansk are of even larger magnitude with a per capita GRP average decrease of 52% (\$3,355).

Empirical Strategy

This section presents the SCM as developed by Abadie and Gardeazabal (2003) and later refined by Abadie, Diamond, and Hainmueller (2010). In addition to the identification and estimation strategy, we discuss advantages of the SCM as well as its limitations especially related to inference.

The true causal impact of a conflict on per capita GDP is given by outcome differences between Ukraine after the war and its counterfactual without the war. The SCM builds upon the potential outcome approach (Rubin 1974) to estimate this counterfactual, 'synthetic' Ukraine, by weighting units in the control group before the war to resemble Ukraine in all outcome-relevant variables, in particular observed time-varying covariates and a set of pre-intervention outcomes. Once the control group is weighted to predict Ukraine's per capita GDP path before the war, post-war differences would only be due to the war if Ukraine's per capita GDP is accurately fitted by the synthetic control pre-war. Our main parameter of interest is the Average Treatment effect on the Treated (ATT) over the periods after treatment, which can be computed as the post-war average difference between the observed outcome of Ukraine and synthetic Ukraine (Gobillon and Magnac 2016; Abadie, Diamond, and Hainmueller 2010).

Consider $i = 1, \dots, J + 1$ countries and $t = 1, \dots, T$ time periods with $1 \leq T_0 < T$ pre-war periods, and define Y_{it}^N to be the per capita GDP of Ukraine $i = 1$ in time t , if not exposed to the war. Let Ukraine be the only recipient of the war, and let any other $j = 2, \dots, J + 1$ country be unaffected by the conflict for a total of J unaffected units. Note that SCM assumes that no country anticipates the war's outbreak before the time period T , and that there are no spillover effects of the conflict on the J control regions after the war (known as Stable Unit Treatment Value Assumption, SUTVA). We further denote the observed outcome for unit i at time t as $Y_{it} = Y_{it}^N + \alpha_{it}D_{it}$ where D_{it} serves as a conflict indicator taking value 1 for Ukraine after 2012 and 0 otherwise. The war causal effect to be estimated is given by the Treatment effect on the Treated, $\tau\tau_t = Y_{1t} - Y_{1t}^N$ for $t > T_0$, and the empirical challenge is to reconstruct the counterfactual Y_{1t}^N , i.e. the post-treatment outcome of the treated unit had it not been treated. Once the counterfactual outcome, \hat{Y}_{1t}^N , is estimated, the ATT over the $T - T_0$ periods after treatment is computed as $\hat{\alpha}_1 = \frac{1}{T - T_0} \sum_{t > T_0} (Y_{1t} - \hat{Y}_{1t}^N)$.

Consider a $(J \times 1)$ vector of optimal weights $W^* = (w_2^*, \dots, w_{J+1}^*)'$ with $w_j \geq 0$ for $j = 2, \dots, J + 1$ and $w_2 + \dots + w_{J+1} = 1$ for J control units such that $\hat{Y}_{1t}^N = \sum_{j=2}^{J+1} w_j^* Y_{jt}^N$. The synthetic control method recreates this counterfactual with a convex combination of untreated units, i.e. $\hat{Y}_{1,t>T_0}^N = \sum_{j=2}^{J+1} w_j^* Y_{j,t>T_0}^N$. The aim of this analysis is to obtain the ATT over the periods after treatment defined as:

$$\hat{\alpha}_1 = \frac{1}{T - T_0} \sum_{t>T_0} \left[Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt} \right]. \quad (1)$$

The estimation of the optimal W^* follows a nested optimization procedure. First, an inner optimization minimizes the Euclidean distance between X_1 and X_0W , $(r + k) \times 1$ and $(r + k) \times (J)$ matrices, respectively, containing k covariates and r linear combinations of pre-war outcomes used as predictors (2):

$$W^* = \underset{w}{\operatorname{argmin}} \|X_1 - X_0W\|_V = \sqrt{(X_1 - X_0W)'V(X_1 - X_0W)}, \quad (2)$$

where V is a $(r + k) \times (r + k)$ symmetric diagonal matrix with non-negative components, in which the diagonal elements $v = (v_1, \dots, v_{r+k})$ are the predictor weights assigned to the fitted pre-war variables. In an outer optimization, V^* can be estimated such that the Mean Squared Error (MSE) of per-capita GDP outcomes is minimized for pre-treatment periods according to $V^* = \underset{v}{\operatorname{argmin}} (Y_1 - Y_0W^*(V))'(Y_1 - Y_0W^*(V))$, where Y_1 denotes pre-war outcomes of Ukraine and Y_0 refers to linear combinations of pre-war outcomes of control countries, which can be, e.g. averaged over some pre-war periods. The SCM identifying assumptions are twofold. First, the outcome of all countries is required to follow a linear model like, e.g. a factor model including interactive fixed effects that capture time-varying unobserved heterogeneity (see Abadie, Diamond, and Hainmueller 2010; Ahn, Lee, and Schmidt 2013). Since Abadie and Gardeazabal (2003) introduce the SCM using GDP as the dependent variable, we consider this assumption as fulfilled (see, e.g. Costalli, Moretti, and Pischedda 2017; Horiuchi and Mayerson 2015 for similar choices). Second, there exist optimal (non-negative) weights (smaller than and adding up to one) that build the synthetic control as a convex linear combination of control countries matching a set of covariates and outcomes pre-war. This is violated in the presence of interpolation bias, i.e. if the synthetic control obtains weights for countries that largely differ in terms of unobservable confounders that may trigger any change in the outcome. In our context, confounders could consist of, e.g. unobserved time-varying factors driving both GDP and the conflict. To avoid the interpolation bias, we restrict the control group to countries of the former Soviet Union and Eastern Bloc which are not treated with the Donbass war or other shocks, as they most accurately reflect the Ukrainian economy, and we exclude Russia because it is part of the Donbass war, of the 2014 annexation of Crimea, and the consequent economic sanctions imposed by the European Union and the United States. Therefore, provided that the number of pre-war periods is large and interpolation bias is not present, the synthetic control approximately fits Ukraine also in its individual time-varying heterogeneity (Abadie, Diamond, and Hainmueller 2010). In such cases, the SCM provides unbiased estimates of the counterfactual with more identification power than traditional regression methods accounting only for time-invariant unobserved differences (Gobillon and Magnac 2016).

We perform standard statistical inference and robustness analyses by (a) in-space placebo tests, and also (b) in-time tests. In the latter case (b), we apply the SCM on Ukraine's outcome pre-war as a means to uncover likely confounding effects of two events: the 2009 gas disputes with Russia, and the 2004 Orange Revolution. In the former case (a), we build a synthetic control for each country in the control group, and we estimate the corresponding ATT (Abadie, Diamond, and Hainmueller 2010). We compute empirical p -values as the probability to obtain ATTs at least as large as the treated unit's (in

absolute terms), i.e. $\frac{\sum_{i=1}^{J+1} \mathbf{1}(|ATT_i| \geq |ATT_1|)}{J+1}$ for $i = 1, \dots, J+1$ where $\mathbf{1}(|ATT_i| \geq |ATT_1|)$ takes value 1 when $|ATT_i|$ is equal or larger than $|ATT_1|$ and 0 otherwise.³

Additionally, we perform in-space placebo tests accounting for the prediction accuracy of the estimated synthetics in the pre-war period (Seifert and Valente 2017). For every country $i = 1, \dots, J+1$, we first compute the pre-war average Mean Prediction Error (MPE) defined as $\frac{1}{T_0} \sum_{t \leq T_0} [Y_{it} - \hat{Y}_{it}^N]$, with \hat{Y}_{it}^N being the synthetic control estimated for every country in the sample. Second, we condition on the MPE to obtain empirical p-values as $\frac{\sum_{i=1}^{J+1} \mathbf{1}(|ATT_i| \geq |ATT_1|)}{J+1}$ s.t. $|MPE_i| \leq |MPE_1|$. Note that this test differs from the inferential technique performed by, e.g. Abadie, Diamond, and Hainmueller (2010) who compute the ratio between post-

and pre-treatment MSE. In this case, the numerator results to be inflated in the presence of, for instance, a large causal effect in one single post-war period, as squaring post-war gaps assign a higher weight to exceptionally large deviations. On the contrary, a counterweight of this effect in the denominator for pre-treatment MSE is unlikely to occur as every placebo country with a much (typically, five to three times) higher MSE than the one of the treated unit is excluded from the computation of the p-values. Motivated by the above as well as by recommendations in Arkhangelsky et al. (2019), Ferman and Pinto (2017), and Firpo and Possebom (2018), MPE-based inference is also presented.

What are the advantages of the SCM over other techniques in our context? Due to the variety of costs that can be attributed to armed conflicts, researchers have adopted three types of evaluation tools: cost-accounting, regression-based, and counterfactual methods (for a detailed overview see, e.g. Gardeazabal 2012; De Groot, Brueck, and Bozzoli 2009). In this paper, we find the SCM to be most suited to evaluate the cost of the Donbass war for at least five reasons. First, unlike cost-accounting methods employed in, e.g. Skaperdas et al. (2009), Bilmes and Stiglitz (2006) and Arunatilake, Jayasuriya, and Kelegama (2001), the SCM does not require multiple calculations of a broad variety of costs, which relies on the availability and quality of governmental data as well as on expertise in listing all types of costs and avoiding double counting. In addition, the SCM allows to perform statistical inference and assess the uncertainty inherent in the cost estimate. Second, in contrast to panel data and time-series methods used by, e.g. Enders, Sandler, and Parise (1992) and Barro and Lee (1994), the SCM is more robust against the presence of unaccounted-for factors that may influence the outcome. By assuming a factor model specification, the SCM allows for a multidimensional unobserved heterogeneity, i.e. for multiple interactive effects, not just additive ones as imposed, e.g. in the difference-in-differences setting (Gobillon and Magnac 2016). In practice, interactive effects can be considered as time-varying fixed effects like, for example, country-specific variations in strategic alliances. Therefore, the SCM generalizes the difference-in-differences method allowing to clearly identify the causal effect of the Donbass war on GDP per capita, disentangling the causal effect from other unobserved time-varying confounders. Third, the SCM improves upon other regression methods because it performs well with small-sized groups, it safeguards against ad-hoc model specification searches, and precludes negative weights, thus, avoids extrapolation outside the support of the data (Abadie 2019). Finally, the SCM estimates sparse weights for the control units allowing to assess their contribution to the counterfactual, and to evaluate directions of potential biases. As a result, the SCM is a well-established causal inference tool, according to Athey and Imbens (2017) one of the most important innovations in the evaluation literature in the last 15 years.

Data

We use yearly country-level panel data over the period 1995–2017 obtained from the World Development Indicators database of the World Bank. The dependent variable used in the SCM

Table 1. Descriptive statistics of variables.

	Mean	Standard Deviation	Maximum	Minimum
TradeDep	0.15	0.15	0.76	0.01
GFCF	23.79	6.37	57.71	5.39
GDPpc	14032.00	8509.13	31339.00	1043.00
Inflation	18.45	59.98	1058.00	-8.52
Polity	4.96	6.25	10	-8
HDI	0.74	0.08	0.81	0.53

analysis is the GDP per capita (GDPpc) in 2011 dollars (PPP). Further, outcome predictors used to match Ukraine in the pre-war period are chosen based on literature review (e.g. Abadie and Gardeazabal 2003). We include inflation measured by the consumer price index due to the prevalence of hyperinflation in post-Soviet states, and its influence on economic development. Further, we control for domestic investment with the gross fixed capital formation (GFCF) as a percentage of GDP, and we measure the dependence on trade with Russia as the sum of the share of exports and imports with the Russian Federation in countries' total international trade (TradeDep). Finally, to account for political and socio-economic resemblance, we also include the Human Development Index (HDI), which is a composite indicator of life expectancy, education, and per capita income, as well as the Polity variable from the Polity IV project dataset in which values equal to 10 (-10) indicate a strongly democratic (autocratic) regime (Marshall 2017). In the SCM estimation, we match on covariates' averages over the 1995–2012 period, and on two outcome lags. The following Table 1 provides data descriptive statistics, while the variables' full description can be found in Table C1 in Appendix III.

The SCM makes a crucial assumption that Ukraine's GDP per capita and all its predictors have to lie within the convex hull spanned by the countries from the donor pool, such that a convex combination of the control countries can actually resemble the treated unit. Figure 1 shows evidence on the presence of such common support. The plot presents boxplots of all predictor variables after their mean normalization, i.e. for each variable we computed $(X_k - \mu_k)$ for $k = 1, \dots, 6$. It can be inferred from the plot that the values of the predictors for Ukraine lie within the spectrum spanned by the units from the donor pool.

As outlined in Section II, synthetic Ukraine is built as a weighted average of former the Soviet Union and Eastern Bloc countries to most accurately resemble its unobserved fiscal and economic conditions over time. We also excluded countries experiencing other shocks in the considered pre-war period. As a result, the control group comprises 17 countries, which are listed in Table 2 of Section IV.

A last note regarding the onset of the Donbass war. The war burst out in 2014, however, it was preceded by the 2013 violent Euromaidan protests and a period of high political instability. For this reason, we assign the year 2013 as the start of the war. Consequently, we estimate the counterfactual over 18 pre-war periods, and we predict the outcome over five post-war periods. As specified in Section II, a precise and robust fit between actual and counterfactual outcome over the whole pre-war period is necessary to guarantee the validity of the counterfactual estimate itself.

Results

Using the SCM, we first show how synthetic Ukraine fits Ukraine's GDP per capita before the war to provide an unbiased counterfactual after the war, and we compute causal effects. Second, we assess statistical significance by placebo tests, and we perform a set of confoundedness as well as sparsity checks. Third, using analogous analyses, we provide further evidence on the war's causal effects for Ukraine's most affected regions.⁴

Table 2 shows that synthetic Ukraine is best reconstructed as a weighted average of four countries, namely, Armenia, Bulgaria, Moldova, and Slovenia – with Moldova and Armenia yielding the highest weights.

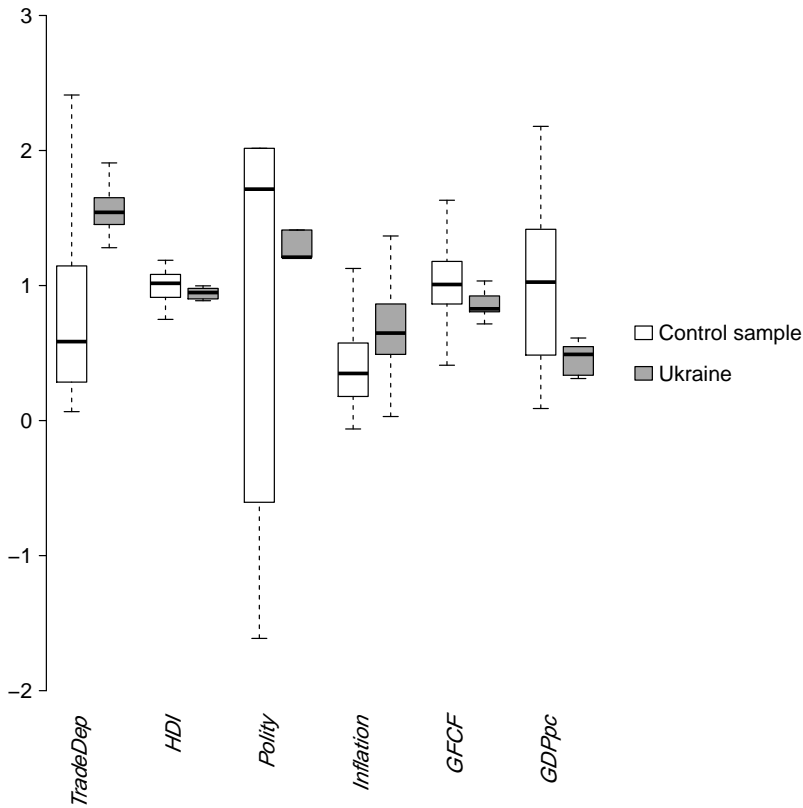


Figure 1. Boxplots of mean-corrected variables.

Table 2. Ukraine's control sample with corresponding weights.

Country	Weight	Country	Weight
Armenia	0.333	Latvia	0
Azerbaijan	0	Lithuania	0
Belarus	0	Moldova	0.452
Bulgaria	0.152	Poland	0
Czech Republic	0	Romania	0
Estonia	0	Slovak Republic	0
Hungary	0	Slovenia	0.063
Kazakhstan	0	Tajikistan	0
Kyrgyz Republic	0		

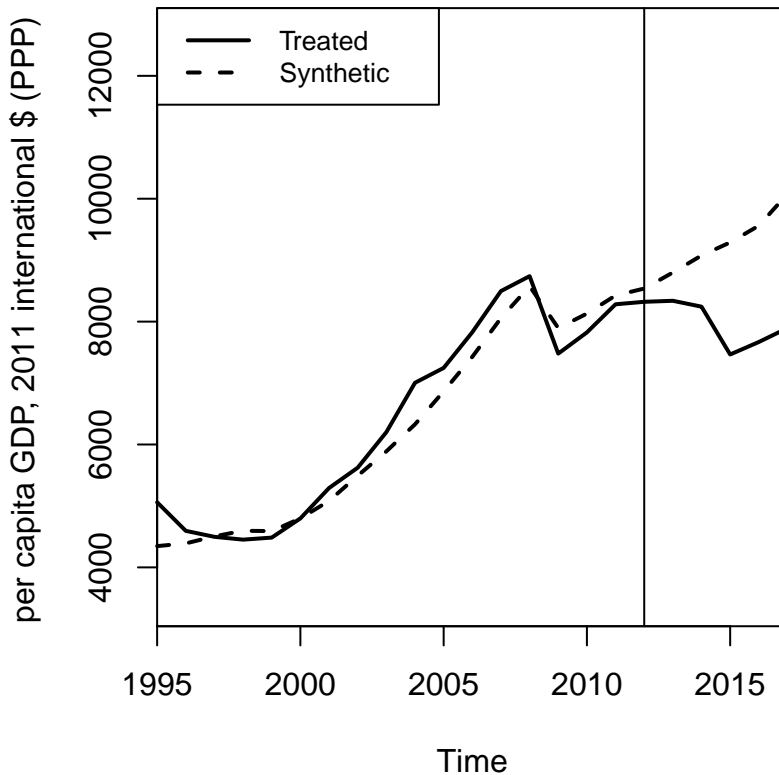
Furthermore, Table 3 displays the results of the estimation, and shows that synthetic Ukraine accurately reproduces mean values of the covariates before the war. As a measure of overall goodness of fit, Table 3 reports the Mean of the Absolute Prediction Errors (MAPE) which amounts to 4% relative to the mean value of Ukraine's per capita GDP in the pre-war period.

Figure 2 displays the trends of per capita GDP of Ukraine and its synthetic counterpart. It clearly shows that both follow a very similar path until 2012 and deviate considerably afterwards. The ATT – computed as the post-war average difference between observed and synthetic GDP per capita – amounts to 15.1%. In particular, yearly differences equal to, respectively, 5.23% (\$460.26), 9.18% (\$832.96), 19.63% (\$1,823.78), 19.80% (\$1,893.38), and 21.67% (\$2,184.13) in 2013, 2014, 2015, 2016, and 2017.

Table 3. Outcome predictor means and weights.

Covariate	Weight	Ukraine		Donor pool
		Real	Synthetic	
Inflation	0.004	36.44	23.04	20.72
GFCF	0.032	20.91	22.89	24.17
TradeDep	0.001	0.23	0.19	0.14
HDI	0.001	0.70	0.68	0.74
Polity	0.001	6.50	6.83	4.78
GDPpc(2000)	0.577	4797.38	4797.03	10650.16
GDPpc(2012)	0.385	8322.17	8538.05	17963.32
MAPE			0.04	

All variables are averaged for the 1995–2012 period except for lagged values of GDP per capita.

**Figure 2.** Trends in GDP per capita: Ukraine vs. synthetic Ukraine.

The SCM does not allow for usual large sample inferential techniques. Instead, it provides a framework for placebo tests. Figure 3 shows the graphical representation of placebo tests for Ukraine and control countries. To be conservative, we exclude from the test control countries with MSE five times higher than the one obtained for Ukraine (as suggested by Abadie, Diamond, and Hainmueller 2010). As a result, we exclude six countries from the plot, i.e. Azerbaijan, Czech Republic, Estonia, Poland, Slovenia, and Tajikistan, which leaves 11 remaining control countries.

Based on placebo tests reported in Figure 3, we conclude that the ATT estimated for Ukraine is larger in magnitude than all placebo ATTs, leading to an empirical p-value of 8% (one over 12) which is the lowest level that we can reach given the size of the considered control group.

Additionally, we further assess the statistical significance of the ATT by computing post-/pre-war MSE ratios. Differently from the test above, this statistic accounts for the goodness of fit of the

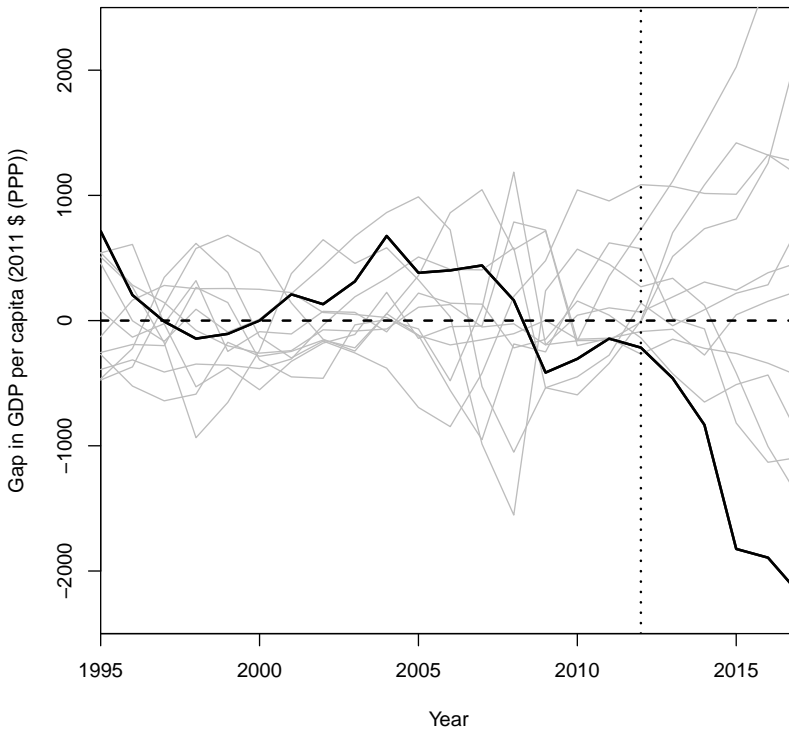


Figure 3. Gaps in GDP per capita in Ukraine and placebo gaps. Countries with poor pre-war fit excluded.

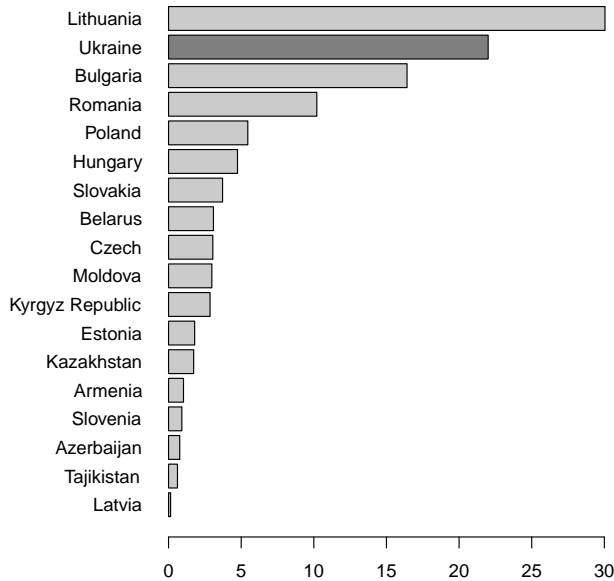


Figure 4. Ratio of mean squared prediction error in post- and pre-war periods.

placebos before the war, and is therefore computed for all 18 units. Figure 4 shows that Ukraine presents the second biggest ratio, yielding a statistical significance level of 11% (two over 18). Finally, as discussed in Section II, since the MSE criterion overweights large gaps, the ATT of each unit is also plotted, for robustness, against its pre-war Mean Prediction Error (MPE), the mean gap before

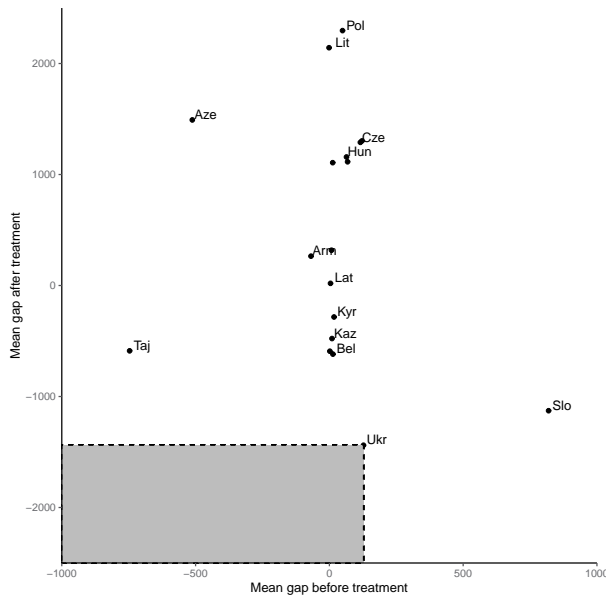


Figure 5. Mean prediction error in post- and pre-war periods (ATT vs. MPE).

treatment.⁵ Figure 5 plots the ATT-MPE test. Since no control unit lies in the highlighted area showing both a more extreme ATT as well as a smaller MPE than Ukraine (in absolute terms), the ATT-MPE test suggests a statistically significant average causal effect at the 5% level (one over 18).

Robustness and Sensitivity

To check whether estimated synthetic Ukraine is robust against different linear combinations of country weights, we perform a Leave-One-Out (LOO) estimation. This means we iteratively build synthetic Ukraine excluding one control unit at the time among those units with positive weights in synthetic Ukraine (i.e. Slovenia, Bulgaria, Armenia, and Moldova). Figure 11 in Appendix II shows that the

LOO synthetic controls closely match the original synthetic Ukraine that includes all control countries, verifying the robustness of the original synthetic. As a result, no country is found to be pivotal to the results. Further, since each LOO synthetic control is above our original estimate, our results can be interpreted as a lower-bound for the war’s causal effects on Ukraine’s GDP per capita. In particular, excluding Moldova (Armenia), the country receiving the (second) highest weight in the original estimation, would cause higher estimates by 10% (20%) on average in the post-war period. Table 4

Table 4. LOO estimation: Ukraine’s per capita GDP losses causal to the Donbass war in each post-war year, and on average in the post-war period (ATT).

Year	Slovenia	Bulgaria	Armenia	Moldova	Original
2013	490.8	649.0	686.6	588.7	460.3
2014	914.9	1083.7	1038.7	866.9	833.0
2015	1932.3	2040.6	2089.1	1982.8	1823.8
2016	1931.0	2103.1	2321.3	2146.8	1893.4
2017	2236.1	2455.7	2553.9	2351.6	2184.1
ATT	1501.0	1666.4	1737.9	1587.4	1438.9

GDP in 2011 international dollars, PPP.

reports all LOO causal effect estimates on Ukraine's per capita GDP in each post-war period and on average over the post-war period (ATT).

The presence of substantial spillovers would violate the no interference assumption (SUTVA) and lead to a bias in the synthetic control estimate. This may be especially the case for Ukraine's neighbouring countries such as Moldova (see map in [Figure 10](#) in Appendix I). However, awareness of the type of potential spillovers allows to evaluate the validity of the counterfactual estimate and the directions of potential biases (Abadie 2019). For instance, if the economic growth of neighbouring countries was negatively affected by the Donbass conflict in the post-war period (perhaps because they diverted demand and investment from Ukraine), this would imply that the synthetic control represents a lower bound on the magnitude of the war's negative effects on Ukraine's GDP. We follow Cao and Dowd (2019) to gauge the potential effects of spillovers on our estimates. The test uses all 18 pre-war GDP per capita values as predictors, and considers Ukraine's neighbouring countries of Belarus, Moldova, Hungary, Poland, Romania, and Slovak Republic as the potentially affected units. Results confirm that our estimates are a lower bound of the war's effect, and indicates that accounting for spillovers would lead to higher GDP losses of 1.8% in 2015, 15% in 2016, and 20% in 2017.⁶ The Discussion Section outlines possible channels through which the Donbass war may (or not) have affected the per capita GDP of countries in the control group.

Moreover, we perform confoundedness checks obtained by iteratively estimating synthetic controls on the pre-war period to account for previous Ukrainian-Russian disputes. This allows to verify if Ukraine's exposure to other external shocks also affects its outcome path. In particular, we analyze two events: the 2009 gas disputes with Russia, and the 2004 Orange Revolution. For this purpose, we iterate the SCM moving the treatment period $T_0 + 1$ to 2009 and 2004, respectively. In this case, we calculate treatment effects only until $T = 2012$ in order to exclude the effects of the Donbass war and obtain 'pure' effects of these events on the Ukrainian economy.

The Orange Revolution is a series of political protests leading to a period of political instability that could have caused a slowdown in Ukraine's GDP. However, estimation results show that the ATT is not statistically significant at conventional levels, namely, 10 over 18 units have a larger ATT (in magnitude) than Ukraine (p -value = 0.55). This is displayed in [Figures 12](#) and [13](#) in Appendix II.

Russian-Ukrainian gas disputes in 2009 represented a trade conflict over gas prices and their terms of export. Since no agreement was reached, Russia interrupted gas supplies to Ukraine which served as a transit country for Europe. Counterfactual estimation reveals a gap between observed and synthetic outcomes in 2009, indicating that Ukraine's GDP per capita would have been higher without the shock. This is shown in [Figure 15](#) in Appendix II. In particular, gas disputes cause a one-time outcome level change in 2009 after which trends are parallel again. Placebo tests indicate that causal effects are significant at the 10% level. Yet, these estimates may be confounded by two factors. First, gas prices increased after 2009, potentially affecting the GDP of control countries. This would lead to a bias in the SC due to violation of the no spillover assumption (SUTVA). Second, the effects of the 2009 financial crisis cannot be disentangled from those of the gas disputes.

Although the 2009 gap may not be entirely attributable to the gas disputes, we compute the confounding effects of the shock on the causal effects of the Donbass war. Being fairly constant for 2009–2012, outcome gaps caused by gas disputes ($\hat{\Delta}_{gas}$) are subtracted from the per capita GDP values of synthetic Ukraine in all consecutive years, and the Donbass war's causal effects are adjusted as shown in [Table 5](#).⁷ Clearly, accounting for gas disputes caused the GDP loss to decrease from original yearly average of \$1,438.9 to \$1,310.86. These results also displayed in [Figure 14](#) in the Appendix II, suggest that the 2009 events led to the overestimation of causal effects of the conflict by an average of 1.21 percentage points (\$128.04). As a result, the lower-bound for Ukraine's per capita GDP foregone due to the war amounts to 13.89%.⁸

Table 5. Per capita GDP differences between Ukraine and its synthetic control including effects of 2009 gas disputes with Russia.

Year t	Per capita GDP \hat{Y}_{1t}^N	Original loss $\hat{Y}_{1t}^N - Y_{1t}$	Per capita GDP $\hat{Y}_{1,t}^{N,corrected}$	Loss excl. 2009 effects $\hat{Y}_{1,t}^{N,corrected} - Y_{1t}$	Difference in losses
2013	8799.18	460.26 (5.23%)	8647.00	308.08 (3.56%)	152.17
2014	9076.43	832.96 (9.18%)	8912.73	669.26 (7.51%)	163.70
2015	9280.71	1823.78 (19.63%)	9146.79	1681.85 (18.40%)	141.93
2016	9561.48	1893.38 (19.80%)	9473.75	1805.65 (19.06%)	87.73
2017	10078.52	2184.13 (21.67%)	9983.85	2089.46 (20.93%)	94.67
Average	9359.26	1438.90 (15.10%)	9231.21	1310.86 (13.89%)	128.04

GDP in 2011 international dollars, PPP.

Regional Synthetic Control Estimates

Since the Donbass war is limited to the territory of only two out of 24 Ukrainian regions (see map in [Figure 9](#) in Appendix I), we estimate the impact of the war on the respective Gross Regional Product (GRP). Results from this estimation would also serve as a reliability check for the causal effects obtained at country level.

Regional SCM estimates are obtained with data from the State Statistics Service of Ukraine, and the first available period is 2004. Limited data availability constrains the choice of the variables included. These are exports of commodities (as a share of GRP), capital investments (as a share of GRP), unemployment rate, and per capita GRP. A detailed description of the data is to find in [Table C2](#) in Appendix III. The values of regions' GRP and capital investment are transformed from the Ukrainian currency (UAH) into international 2011 dollars using the exchange rates given in [Table C7](#) in Appendix III. The control group includes 22 Ukrainian regions with the exclusion of Kyiv City because its economy differs considerably from those of the other regions.⁹ The complete list of the control units can be found in [Table C3](#) in Appendix III.

For the estimation, we use regional panel data from 2004 to 2016. As for the country-level estimation, the treatment is assigned in 2013 to account for anticipation effects. We suspect that although armed conflicts did not start before 2014, there might have been regional tensions and hostilities that influenced social and economic living conditions of the local population. As a result, we match on nine pre-war periods to predict four post-war periods.

[Tables C3](#) and [C6](#) in the Appendix report the estimated unit and predictor weights, respectively, while [Tables C4](#) and [C5](#) show average values of covariates for the Donbass regions, their synthetic counterparts, and the whole control sample mean. It can be inferred that weighted averages accurately reconstruct all the outcome-relevant characteristics of the affected units.

Finally, [Figures 6](#) and [7](#) plot the values of GRP per capita for Donetsk and Luhansk along with their synthetic counterparts. While in both cases observed and synthetic outcomes follow almost an identical trend until 2012, observed outcomes severely drop post-war. This estimation shows that, due to the Donbass war, Donetsk's and Luhansk's average GRP for 2013–2016 decreased by 42% (\$4,294) and 52% (\$3,355), respectively.

Statistical significance of these causal estimates is confirmed by a series of placebo tests as shown in [Figure 8](#), and [Figures 16](#) and [17](#) in Appendix III.

Compared to the country-level estimation, assumptions for the regional case are weaker, in particular, SUTVA. However, obtaining plausible causal estimates seems likely because Donetsk and Luhansk are the only regions directly affected by the fights. Following Cao and Dowd (2019), we test for spillovers in the potentially affected neighbouring regions of Dnipropetrovsk, Kharkiv, and Zaporizhzhya for Donetsk, and Kharkiv for Luhansk (see map in [Figure 9](#) in the Appendix I) using all 9 pre-war GDP per capita values as predictors. We find that adjusting our estimates to account for spillovers would increase the magnitude of the ATT by 13% for Donetsk and 11% for Luhansk. Thus, similarly to the country-level estimation, the test shows that our estimates are a lower bound of the war's causal effects.

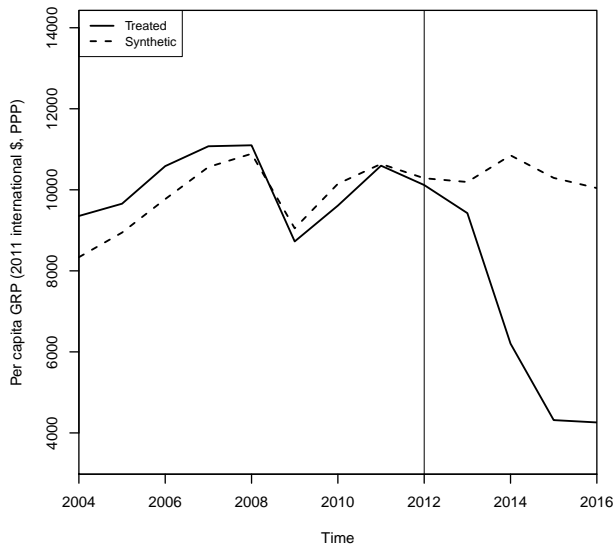


Figure 6. Per capita GRP trends in Donetsk vs. its synthetic counterpart.

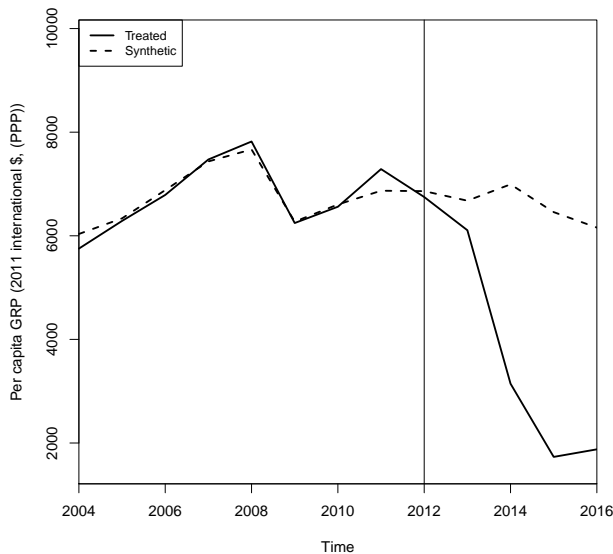


Figure 7. Per capita GRP trends in Luhansk vs. its synthetic counterpart.

Discussion

Our results from the counterfactual estimation show that Ukraine's per capita GDP experienced a significant decline due to the Donbass war and, in its absence, would have instead followed a rather stable, slowly increasing trend. Importantly, we estimate that the gap between what actually happened in the Ukraine's economy and its counterfactual widens over the 4 years after the official start of the war in 2014.

Although our study does not aim to statistically identify the particular GDP components that contributed to its decline, we hereby discuss possible mechanisms underlying the causal impacts of the Donbass war, and provide external anecdotal and formal evidence that supports our results. Additionally, we discuss the role of (I) economic sanctions and (II) military expenditures together with our study's limitations.

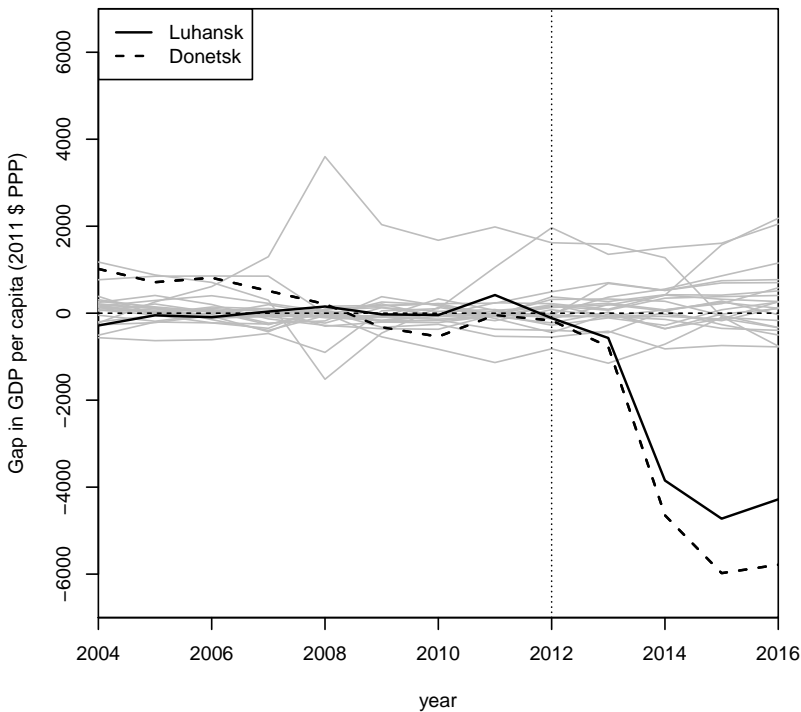


Figure 8. Gaps in per capita GRP in Donetsk, Luhansk and placebo gaps.

Mechanisms Underlying the GDP Decline Causal to the War

There are several explanatory factors for the negative causal effects of the Donbass war on Ukraine's GDP per capita. These are, for instance, disruption to production, trade and employment, agricultural and financial losses, compression of public expenditures, and a partial military mobilization coupled with growing political instability.

Since its outbreak, the war took a heavy toll on Ukraine's economy especially due to trade disruptions and diverted government spending. Between May and September 2014, the European Bank for Reconstruction and Development adjusted its predictions on Ukraine's GDP loss from 7 to 9% (Reuters 2014). In fact, only a few months after the war's beginning, most of eastern Ukraine's core industries and infrastructure has been either shut down or destroyed. Also, physical losses as well as water and electricity cuts made large facilities such as coal and power stations inoperable. For instance, coal mines have flooded because power cuts prevented water extraction, and the fewer transfers of the Donbass' exports of coal, steel and other industrial goods became more costly due to the destruction of bridges, roads and railways. As a result, during the war, the Donbass – previously Ukraine's largest industrial centre – drastically reduced its contributions to the country's economy.

Several institutions and governmental sources reported estimates of the ongoing economic costs of the Donbass war. In September 2014, Prime Minister Arseniy Yatsenyuk reported that the Donbass war was costing the government 6.15 million dollars a day (Wilson 2015). Donetsk's politician and economist Alex Ryabchyn referred to a variety of reasons for such costs (Kuznetsov 2014). He reported that (i) several manufacturing industries depend on raw materials coming from the Donbass, (ii) exports of coal, steel, and power heavily depend on the Donbass' output and transportation infrastructure, and (iii) one-third of Ukraine's market is fostered by trade with Russia. In the latter respect, the index of merchandise exports between Ukraine and Russia has fallen by 80% over 2013–2016 (Hornish 2019).

Moreover, investors usually shy away in the presence of conflicts, and the confidence in the overall economy plummets. In the Donbass case, real foreign direct investment stagnated at about 1% of GDP on average over 2014–2018 (Åslund 2019). Furthermore, Ukraine's energy sector was also largely damaged by the failure of the Minsk peace process and the 2017 trade blockade against the Donbass. The latter was operated by pro-Russian separatists to block the transport of raw materials including, in particular, anthracite coal from the Donbass to the rest of Ukraine. This resulted in major production breaks for companies not only in eastern but also in western Donbass due to the interconnection of their production cycles (for more details see, e.g. Kostanyan and Remizov 2017).

As an additional consequence of the 2017 blockade, Ukraine scored higher in terms of internal conflicts fought, and growing political instability which proxies for the propensity of a government collapse (IEP 2018). Especially if coupled with increased internal conflicts, political instability has been shown to damage a country's economy by reducing investment, lowering the rates of productivity growth and, to a smaller extent, of physical and human capital accumulation (Hussain 2014).

Yet, important questions remain open, namely, whether the negative effects of the Donbass war on Ukraine's economy have been reinforced by the government's mismanagement of the conflict and a weak external environment during the war. The latter includes, for instance, lower global commodity prices that resulted in a deterioration of Ukraine's terms of trade.

On the governmental side, instead, the World Bank reports that structural imbalances such as an already consolidated fiscal deficit were negatively adjusted in response to the war shock (World Bank, 2017). This likely resulted in a compression of domestic demand, increased public and guaranteed debt, and severe currency depreciation which induced deposit outflows, rising levels of nonperforming loans, and large numbers of bank failures, further reducing confidence in the economy. In this respect, an empirical study by Kochnev (2019b) estimates a nonlinear and on average positive association between Ukraine's stock market performance during the war and investors' expectations on the prospect of conflict resolution.

In light of all the above, we can expect that not only the Donbass but also other Ukrainian regions were damaged by the conflict, in which case our estimated average GDP decline (43% for Donetsk and 52% for Luhansk) would represent an underestimate of the true causal effects for the Donbass region. Interestingly, using a difference-in-differences design and luminosity data to proxy for economic development, Kochnev (2019a) reports similar estimates, namely, a decrease in economic activity by 38% and 51% in the Donetsk and Luhansk regions, respectively.

Economic Sanctions and Military Expenditures

One main limitation of our study is the possible violation of the SCM identifying Stable Unit Treatment Value Assumption (SUTVA). In particular, SUTVA requires the absence of spillover effects of the Donbass war, the treatment, on the GDP of countries and regions in the control group. If SUTVA is violated, the synthetic control built as a linear combination of untreated, though spilled over outcomes would be a biased estimate of the counterfactual in the post-war period. We identify two main unaccounted-for factors that may cause such spillovers, namely economic sanctions and military expenditures.

Concerning the first, we refer to the economic sanctions imposed on the Russian Federation by the EU in the aftermath of Crimea's annexation in 2014 and the Donbass war. These sanctions may have had an impact not only on the Russian Federation but also on the EU, especially because target and sender countries are economically interdependent and have cooperative political relations (Kaempfer and Lowenber 2007; Drezner 1999).¹⁰ In light of this, our concern is that the GDP of countries and regions in the control group could be impacted, although indirectly, by these sanctions. However, we argue that this is likely a minor issue for at least three reasons. First, while sanctions affect exports directly, they only indirectly impact the GDP which is more sensitive to other dynamics such as taxation and countries' overall performance (Giumelli 2017). Second, sanctions'

effects are shown to be strongest in the very short-run, which indicates that GDP values after 2015 are most likely unaffected (Dizaji and van Bergeijk 2013). Third, although sanctions' costs are difficult to identify and disentangle from countries' performance, the analysis of export data suggests that only a few of our control countries experienced changes in exports that may be attributable to these sanctions. Specifically, a study by Giumelli (2017) finds that, on the one hand, exports of Germany, Italy, France, the Netherlands and Poland seem to be especially hit by the sanctions, with the most severe drop in 2015 compared to 2013. On the other hand, exports of Slovenia, Luxembourg and Romania were affected the least. This brings us to the conclusion that the 2014 sanctions may have had only mild, if any, consequences on the GDP of countries in the control group. Moreover, due to the ambiguity about the direction of the effect in each country, we cannot provide an upper or lower bound for the SC estimator as, e.g. indicated in a similar case by Costalli, Moretti, and Pischedda (2017). Therefore, future research is needed to shed light on the direction and magnitude of sanctions' potential spillovers.

Another source of spillover effects might be changes in military spending in control countries. A strand of the literature shows that neighbouring states may perceive conflicts as a threat and, thus, increase military expenditures (Smith 2014; Collier 2007) which in turn may impact their economic growth (Zielinski, Fordham, and Schilde 2017; Murdoch and Sandler 2004). Although similar studies to this commonly assume that indirect spillovers are of negligible magnitude (Costalli, Moretti, and Pischedda 2017; Horiuchi and Mayerson 2015), we cannot ignore that the Donbass war increased the political instability especially in post-Soviet republics and the Baltic states (Eröss, Kóvaly, and Tátrai 2016; DeGhett 2015).

However, also in this case, we believe that changes in military expenditures have only a minor, if any, effect on the results for the following reasons. First, the war's outbreak coincided with multilateral agreements made at the 2014 NATO Summit in which member states were urged to increase their military burden up to 2% GDP share. As a consequence, countries lagging behind this goal made the most significant investments in this sector with both Latvia and Lithuania increasing their military burdens from 0.9% in 2013 up to 1.7% in 2017. The same holds true for Romania and Poland which increased their military burdens over the same period from 1.3% up to 2%, and from 1.8% up to 2%, respectively. Thus, the NATO agreement largely explains the variability of military spending over the years 2014–2017 in Eastern Europe. Secondly, in the case of post-Soviet republics, increased military burden occurs according to bilateral military agreements with the Russian Federation, external military investments from Moscow, and modernization programs within the Collective Security Treaty Organization (CSTO) which is also led by Russia (Klein, 2019). Third, although military spending may have indirect effects on GDP growth, the size and the direction of this effect are ambiguous. On the one hand, the literature suggests that increased military expenditure has positive effects on economic growth through increased manufacturing output, inciting technological progress and innovation (Barro and Lee 1994). On the other hand, it can be argued that its effect on investment, capital formation and resource allocation is adverse, indirectly curbing other sectors of the economy and inhibiting long-term economic growth (Knight, Loayzan, and Villanuev 1996). Despite the many studies on the topic, there is lack of consensus on the impact of military burden on countries' GDP growth (Herrera and Gentilucci 2013). As a result, observing no sudden change in the 2014 GDP growth among the control countries, we conclude that the effect of changes in military spending on the donor pool's GDP, if present, is likely negligible. Yet, future research is needed to investigate its magnitude, significance, and spatial dispersion.

Conclusions

The Donbass war has taken a severe toll on Ukraine, claiming over 10,000 casualties and triggering a severe economic recession. Yet, to the best of our knowledge, there is no empirical evidence on the overall costs incurred by Ukraine as a result of the war. Thus, the goal of this paper is to start filling

this gap by estimating Ukraine's GDP foregone due to the Donbass war, and discussing mechanisms underlying this causal effect.

Results from the counterfactual estimation by the synthetic control method indicate that the Donbass war led to a considerable decline of Ukraine's economy. Namely, we estimate that, due to this war, the country's per capita GDP decreased by 15.1% (\$1,438.90) on average over the period 2013–2017. Statistical significance of the causal estimates is shown by multiple placebo tests, and robustness is checked by leave-one-out estimations, and confoundedness analyses. In particular, we find that the 2009 gas disputes with Russia and the financial crisis in the same year may lead to overestimated causal effects. As a consequence, the estimated lower-bound of Ukraine's per capita GDP foregone due to the war amounts to 13.89%.

Additionally, we show that the conflict affected the Donbass area severely. Over the period 2013–2016, the per capita GRP of the Donbass regions of Donetsk and Luhansk is found to be, on average, 47% (\$3,825) lower compared to its synthetic counterpart not affected by the strife. This result is in line with the estimated causal effects at country-level.

Several interesting issues are still outstanding. First, this paper focuses on quantifying the economic consequences of the conflict on per capita GDP. Although these account for a large part of direct and indirect costs of the war, we do ignore human capital, social, and psychological effects as well as migration dynamics which start to occur in the longer run. Moreover, given the ongoing nature of the conflict at the time of writing, the continuation of this study should be pursued as more data become available. It should be assessed how the costs evolve over time, in particular, whether the estimated destructive effects increase in scope as more workforce and investment flee the state. This knowledge is crucial to mitigate the damaging consequences of the conflict, and target aid and investment more effectively. These issues are under investigation by the authors.

Notes

1. For a map of the conflict, see [Figures 9 and 10](#) in the Appendix I.
2. As a matter of fact, despite more than ten thousand casualties and continuous fights (OHCHR 2017), neither Ukraine nor any other entity declared the war status: the Ukrainian government referred to it as an anti-terrorist operation, and, on the other side, Russia admitted that intelligence military forces were sent to Ukraine, but denies the use of regular troops (Walker 2015). As a result, although there are many signs indicating Russia's involvement in the Donbass war (Rácz 2015), the lack of undeniable confirmation from Kremlin's side complicates the relationship between both countries and hinders any mitigation of the conflict.
3. When the magnitude of ATT_1 is extreme relative to the permutation distribution, we obtain the smallest p-value of size $\frac{1}{J+1}$.
4. We use the statistical software R and, particularly, the Synth package (Abadie, Diamond, and Hainmueller 2011).
5. Since this test explicitly accounts for the prediction accuracy of all synthetics in the pre-war period, we do not exclude control countries with MSE five times higher than the one obtained for Ukraine.
6. We thank an anonymous referee for suggesting this test.
7. Causal effects of the gas disputes are computed as $\hat{\Delta}_{gas} = 1/4 \sum_{t=2009}^{2012} (Y_{1t} - \hat{Y}_{gas,t}^N)$, and the corrected counterfactual outcome accounting for such shock is $\hat{Y}_{1,t}^{N,corrected} = \hat{Y}_{1t}^N - \hat{\Delta}_{gas}$ for $t > 2012$.
8. These results are robust to an alternative correction strategy, namely, estimate Ukraine's SC and ATT after correcting Ukraine's outcomes for the causal effects of the disputes.
9. Kyiv City is Ukraine's capital and its biggest, most affluent agglomeration. It accounts for nearly a quarter of the country's capital investment and its GRP per capita is roughly three times higher than Ukraine's average.
10. In fact, Russia is EU's third largest trade partner, and the EU is Russia's largest one.

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Appendix

I Maps



Figure 9. Ukraine's geographical location in Europe. The darker area in Ukraine represents the Donbass.



Figure 10. Ukraine's administrative division map. Darker areas represent the two Donbass' regions of Donetsk and Luhansk.

II Graphs

Figure 11 shows the Leave-One-Out (LOO) estimations: The solid black line represents Ukraine's observed GDP per capita, dashed black line is the original synthetic Ukraine, and grey lines are the LOO synthetic controls estimated by excluding one control unit at the time among those units with positive weights in the synthetic Ukraine (Slovenia, Bulgaria, Armenia, Moldova).

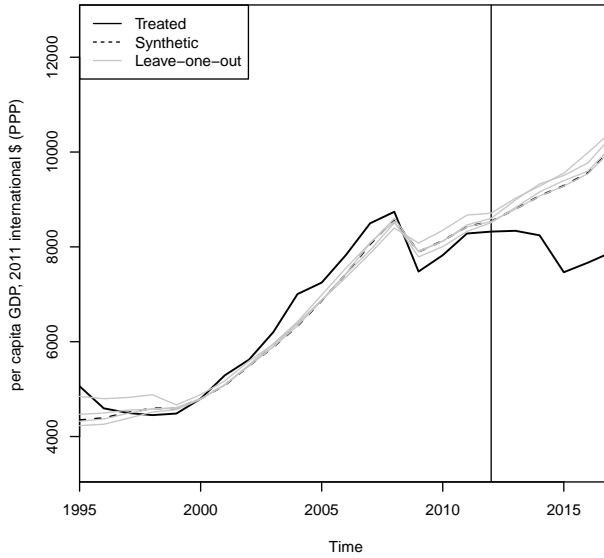


Figure 11. Leave-one-out distribution of synthetic controls for Ukraine.

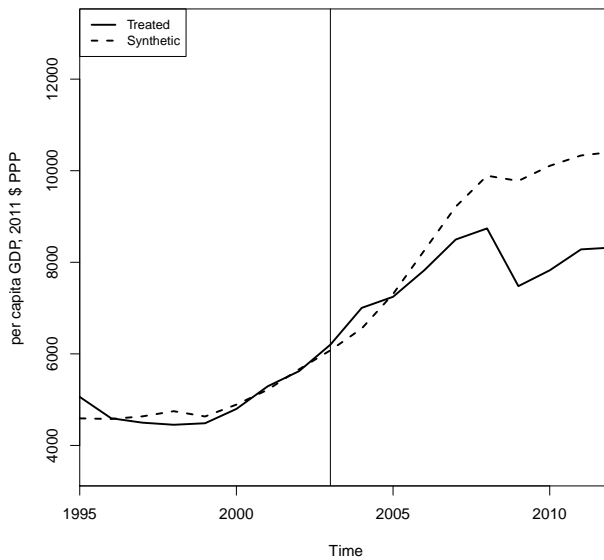


Figure 12. The 2004 Orange Revolution: per capita GDP trends in Ukraine vs. synthetic Ukraine.

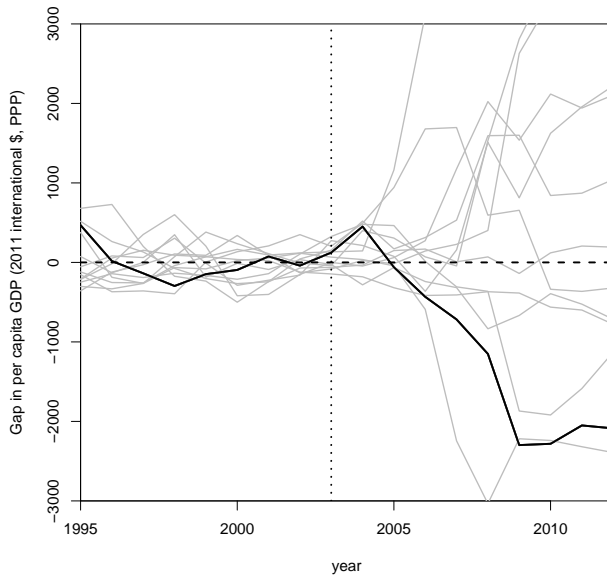


Figure 13. The 2004 Orange Revolution: Gaps in per capita GDP in Ukraine and placebo gaps.

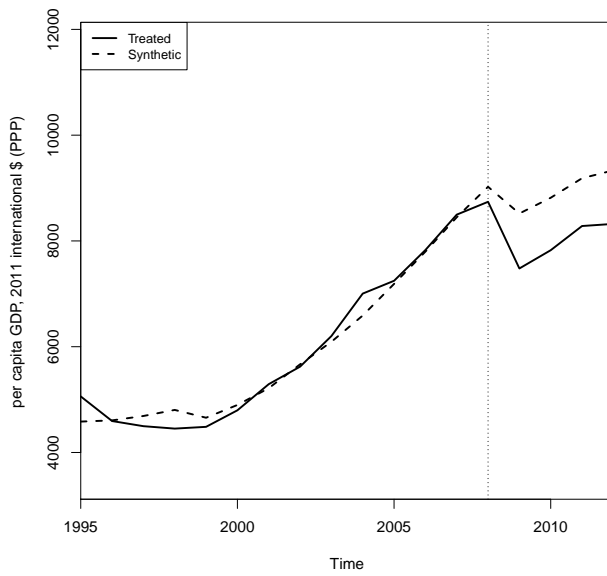


Figure 14. The 2009 gas disputes: Per capita GDP in Ukraine vs. synthetic Ukraine.

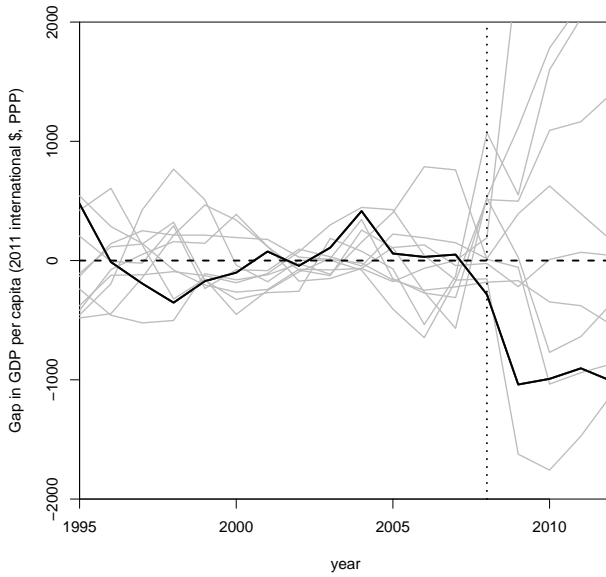


Figure 15. The 2009 gas disputes: Gaps in per capita GDP in Ukraine and placebo gaps.

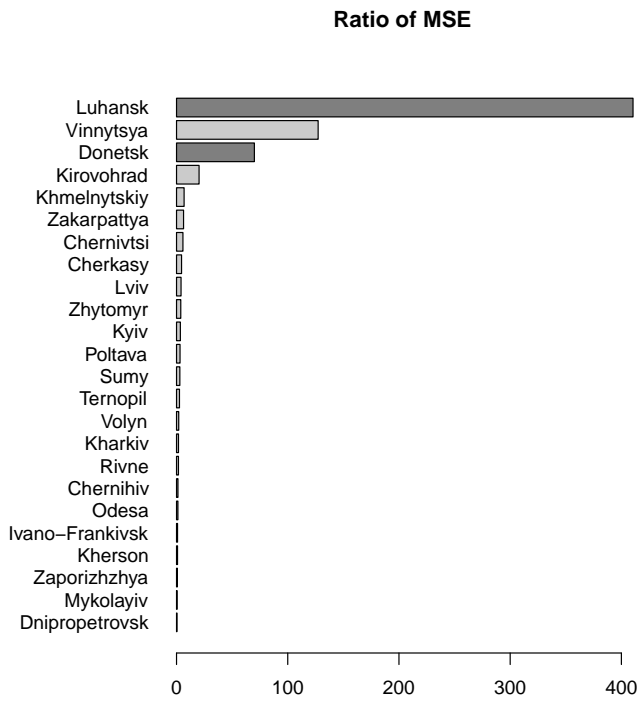


Figure 16. Ratio of mean squared prediction error in post- and pre-war periods for the Donbass regions of Luhansk and Donetsk.

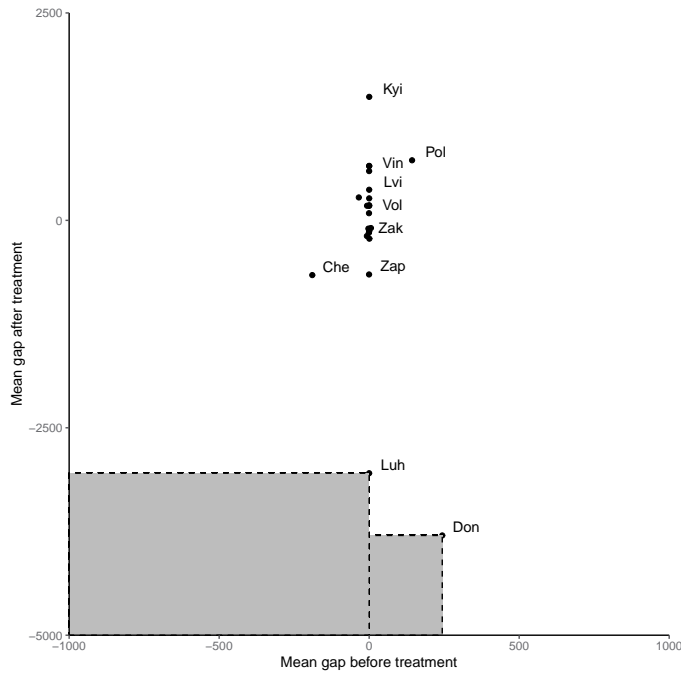


Figure 17. Mean prediction error in post- and pre-war periods (ATT vs. MPE) for the Ukrainian regions. No control unit lies in the highlighted area showing both a more extreme ATT as well as a smaller MPE than Luhansk and Donetsk (in absolute terms).

III Tables

Table C1. Data description of variables used in the country-level estimation.

Variable	Description
Inflation	Inflation, consumer prices (annual %)
GFCF	Gross fixed capital formation (% of GDP)
Polity	Polity IV Individual Country Regime Trend
HDI	Human Development Index
TradeDep	Sum of exports and imports with the Russian Federation (% of GDP)

Data source: World Bank's World Development Indicators; Marshall (2017).

Table C2. Data description of variables used in the regional-level estimation.

Variable	Description
Export	Exports of commodities (% of GRP)
Investment	Capital investment by region (% of GRP)
Unemployment	Unemployment rate of population (results of a sampling survey population of economic activity)
GRP	Per capita gross regional product (2011 international dollars, PPP)

Data source: State Statistics Service of Ukraine (<http://www.ukrstat.gov.ua>).

Table C3. Donetsk's and Luhansk's control sample with corresponding weights.

Region	Donetsk	Luhansk	Region	Donetsk	Luhansk
Dnipropetrovsk	0.351	0.135	Poltava	0.513	0.016
Chernivtsi	0	0.005	Zakarpattia	0	0.411
Zaporizhzhya	0.135	0.290	Odesa	0	0.006
Volyn	0	0.005	Zhytomyr	0	0.004
Ivano-Frankivsk	0	0.008	Kyiv	0	0.021
Kirovohrad	0	0.005	Lviv	0	0.006
Mykolayiv	0	0.062	Rivne	0	0.004
Sumy	0	0	Ternopil	0	0
Kharkiv	0	0.005	Kherson	0	0.003
Khmelnyskiy	0	0.004	Cherkasy	0	0.006
Chernihiv	0	0			

Table C4. Donetsk's per capita GRP predictor means, and Mean Absolute Prediction Error (MAPE) relative to the mean outcome value pre-war.

Covariate	Treated	Synthetic	Control sample
Export	25.36	18.74	9.61
Unemployment	7.94	7.85	8.50
Investment	18.32	21.78	23.60
GRP	10,091	9,847	6,014
MAPE		0.06	

All variables are averaged over the 2004-2012 period.

Table C5. Luhansk's per capita GRP predictor means, and Mean Absolute Prediction Error (MAPE) relative to the mean outcome value pre-war.

Covariate	Treated	Synthetic	Control sample
Export	22.77	19.29	9.61
Unemployment	6.90	7.89	8.50
Investment	20.79	20.79	23.59
GRP	6,773.60	6,773.70	6,013.95
MAPE		0.02	

All variables are averaged over the 2004-2012 period.

Table C6. Predictor weights in the regional estimations.

Covariate	Donetsk	Luhansk
Export	0.075	0.001
Unemployment	0.733	0
Investment	0	0.408
GRP	0.191	0.591

Table C7. Exchange rates between UAH and international 2011 dollars.

Year	Rate	Year	Rate
2004	0.963	2010	0.332
2005	0.773	2011	0.291
2006	0.673	2012	0.26
2007	0.548	2013	0.249
2008	0.426	2014	0.223
2009	0.377	2015	0.161
		2016	0.132

Own elaboration based on Ukrainian GDP data obtained from Ukrainian State Statistics Service in UAH and corresponding data obtained from World Bank in international 2011 dollars.