Harvesting the Blast Craters

Ukraine's Post-War Recovery Potential through Synthetic Control and Input–Output Modeling

By

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Abstract

Research Question: *How can a lost decade of economic growth in Ukraine be reversed — and if so, which economic sectors should lead the charge?*

This thesis develops an empirical framework to assess the economic cost of war for Ukraine and guide post-conflict recovery planning through a combined Synthetic Control Method (SCM) and Input–Output (IO) model. Using macroeconomic data from 1996 to 2023, a counterfactual "synthetic Ukraine" is constructed from a donor pool of 18 regional peers to estimate the trajectory Ukraine's economy would potentially have followed in the absence of war. By 2021, the analysis shows that Ukraine's GDP per capita (PPP) was approximately $1,007 below its synthetic equivalent, implying a one-year output loss of $44.6 billion, equivalent to ₴325.6 billion in lost GDP, and a cumulative loss of $1.1 trillion over the decade-long conflict.

The SCM estimate is then converted and used as a target output for IO-based reconstruction modeling. Instead of injecting fixed sectoral stimuli, the model reverses the Leontief model to determine the sector-specific final demand required to close the output gap between real and synthetic Ukraine. Recovery scenarios simulated across Ukraine's 42-sector IO structure include *infrastructure-led*, *industrial*, *agricultural*, and *balanced* pathways. Required injections of final demand range from ₴708 billion (balanced) to over ₴1.1 trillion (industrial), with total output requirements ranging from ₴1.09 trillion to exceeding ₴1.8 trillion.

The findings highlight that no recovery strategy is universally "optimal." The effectiveness of reconstruction depends not only on sectoral multipliers but also on realistic supply conditions, such as available labor, capital, and institutional capacity, factors that are out of the scope of this thesis. Nevertheless, the SCM-IO framework offers a transparent and adaptable tool for scenario-based recovery planning once updated post-war data becomes available, supporting both strategic vision and implementation in Ukraine's short-term reconstruction.

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Chapter 1: Introduction

For over a decade, starting with the annexation of Crimea in early 2014, escalating through years of warfare in the Donbas, and culminating in the full-scale invasion of 2022, Russian aggression against Ukraine represents one of the most dramatic economic shocks experienced by a European sovereign state in recent history. Beyond the immediate humanitarian disaster, the war has caused substantial economic damage, including the destruction of infrastructure, labor displacement, trade disruption, and a historic contraction in output. Ukraine's real GDP fell by more than 30% in 2022 alone (National Bank of Ukraine, 2023), wiping out a decade of previous gains. Yet beyond the visible physical destruction lies a deeper, less tangible cost – the long-term loss of output and income due to displaced human capital, destroyed production capacity, and structural disruption. Quantifying this loss for a recovery strategy is a moral responsibility and a policy imperative.

This thesis develops an empirical framework to estimate the economic cost of war and chart a viable, sector-sensitive recovery path. It unfolds in two phases. Initially, the Synthetic Control Method (SCM) constructs a counterfactual trajectory for Ukraine's GDP per capita (PPP), drawing on a donor pool of 18 peer economies that are unaffected by major conflicts. By contrasting actual and synthetic trends from 2014 to 2023, the analysis reveals that by 2021, Ukraine's GDP per capita (PPP) was approximately $1,007 lower than its synthetic benchmark. Using World Bank (2024) population figures (44.3 million), this corresponds to a nominal GDP deficit of $44.6 billion, which is equivalent to roughly 6% of the total GDP (PPP) of $746.5 billion. With the 2021 PPP conversion factor of 7.3, this shortfall amounts to ₴325.6 billion in local currency (World Bank, 2024), the Ukrainian hryvnia (₴, UAH), or approximately 6% of the gross value added (₴4.6 trillion) as reported by the State Statistics Service of Ukraine (2023). Throughout the post-2014 period, cumulative nominal losses to Ukraine are estimated at $1.1 trillion (or $950 billion in net present value discounted using 2013 US CPI), consistent with empirical estimates from the Kyiv School of Economics (Stepanov, Fedets, Tokar, & Sukhomud, 2024).

In the second phase, the projected GDP gap for 2021 acts as a benchmark for a reverse-engineered Input–Output (IO) model. Rather than simulating random budget injections, the model distributes final demand among Ukraine's 42 economic sectors to reveal the combinations to bridge the gap, leveraging the country's most recent publicly accessible intersectoral structure from 2021 (as of May 2025). Four distinct recovery strategies are analyzed: infrastructure-led, industrial, agricultural, and balanced. The necessary final demand injections vary from ₴708 billion to ₴1.16 trillion, while the total output required ranges from ₴1.09 trillion to over ₴1.86 trillion.

Scenario	Target Output (₴)	Final Demand (₴)	Demand-to-Output Ratio
Infrastructure-Led	1,286,464,465,917	775,886,495,908	0.603
Industrial	1,863,772,217,433	1,159,230,295,891	0.622
Agricultural	1,198,133,758,195	835,324,139,124	0.697
Balanced	1,090,101,344,052	708,473,180,986	0.650

Table 6.1. Cross-Scenario Comparison

Crucially, the analysis shows that output efficiency, measured by the demand-to-output ratio, varies significantly across sectors; however, feasibility also depends on supply-side constraints, such as labor availability and productive capacity. Therefore, the thesis rejects the notion of a universally optimal strategy in favor of scenario-based planning that should consider Ukraine's real-world limitations.

This research presents a twofold contribution. Methodologically, it integrates a causal macroeconomic estimator, SCM, into the traditionally static field of structural IO models, establishing a direct link between counterfactual loss estimation and sectoral planning. Practically, it offers a replicable template for Ukrainian post-conflict recovery planning, based on observed data rather than abstract assumptions. Importantly, it demonstrates how the results of one model can be converted for use in another. While the analysis relies on data from 2021, the most recent year of publicly available IO data at the time of writing, the framework is designed to be updated as new post-war data emerges and as Ukraine's reconstruction advances. By combining macro-level causal inference with micro-structural sectoral modeling, this thesis provides a quantitative toolkit for comprehending not just the losses incurred due to war but also how recovery can be achieved in a way that is economically grounded, scalable, and realistic. It aims to aid policymakers, economists, and planners in rebuilding Ukraine, not just to restore its pre-war condition but to foster a more resilient and efficient economic future — a notion known as 'build back better.'

The remaining sections of this thesis are organized as follows: Chapter 2 reviews relevant literature on the economic analysis of war, synthetic control in causal inference, IO modeling in recovery planning, and the thesis's contributions to the field; Chapter 3 offers historical and economic context regarding Ukraine's evolution since independence, including various political and economic shocks that occurred before and after 2014; Chapter 4 discusses the data and methodological approach in detail, featuring distinct sections on SCM and IO theory and modeling, as well as a transitional link called Intermezzo between the two; Chapter 5 outlines the simulated recovery scenarios; Chapter 6 presents the results, comparing the efficiency and scale of each scenario; Chapter 7 interprets these findings in the context of policy constraints and strategic planning; Chapter 8 serves as the conclusion.

Chapter 2: Literature Review

This chapter examines the literature surrounding the economic impacts of the war in Ukraine, along with the analytical techniques used. By integrating SCM with IO, the thesis presents an innovative, policy-oriented framework for assessing war damage and supporting economic reconstruction efforts.

2.1 Economic Costs of the War in Ukraine

Throughout the conflict, Ukraine has come to symbolize the saying "war never changes," both in theory and through harsh realities. The initial shock between 2014 and 2015, following the annexation of Crimea and the outbreak of war in the Donbas was particularly harsh: Ukraine's GDP dropped by 6.6% in 2014 and an additional 9.8% in 2015 (IMF, 2024). This decline stemmed from the sudden loss of industrial output in the eastern regions, subsequent financial instability, and widespread investor uncertainty. Key industrial sectors heavily concentrated in Donetsk and Luhansk, such as coal mining, metallurgy, and machine construction, experienced considerable disruptions. The currency lost more than 60% of its value from 2013 to 2015, resulting in inflation rates that surpassed 40% in 2015 (Lagarde, 2015). Fiscal pressures increased as the government raised defense spending and social support during a decline in tax revenues. Unemployment soared, and Ukraine sought a $17.5 billion bailout from the International Monetary Fund in early 2015 to stabilize its economy (IMF, 2015). Additionally, despite some moderate recovery over the eight years following the aggression's onset, the full-scale Russian invasion reversed all these advances. Reports from the World Bank projected a GDP decline of over 30% by 2022, with actual figures later revealing a contraction of approximately 29–35% for that year. The socio-economic impacts of this new phase of war have been just as severe, with poverty rates rising from 5.5% to over 24% within two years (World Bank Group, 2024).

The decline in output is worsened by physical and infrastructure losses. According to the Kyiv School of Economics (KSE), Ukraine's direct physical infrastructure damage is estimated at about $155 billion as of early 2024, which includes nearly $59 billion in destroyed housing. However, if we consider wider economic impacts like lost production, halted exports, and capital flight, the overall economic damage stemming from Russia's full-scale invasion surpasses $1.1 trillion (Stepanov, Fedets, Tokar, & Sukhomud, 2024). This amount represents not just damage to physical assets, but also years of missed investments and lost productivity.

The impact has been particularly severe in Ukraine's most productive sectors. According to KSE estimates, commerce has incurred losses of approximately $450.5 billion, followed by construction at $409.9 billion, agriculture at $83.1 billion, energy at $43.1 billion, and transportation at $38.8 billion (Stepanov, Fedets, Tokar, & Sukhomud, 2024). These sectors are not only key drivers of GDP but also essential to employment and export capacity. Exporters have faced challenges due to blocked logistics routes and disrupted ports. Missile and drone strikes have damaged or destroyed warehouses and factories, and intermittent electricity shortages have hindered production across all sectors. These systemic shocks have diminished Ukraine's ability to generate revenue, attract investment, and sustain macroeconomic stability.

The World Bank's assessments from 2025 estimate the total reconstruction cost to be between $486 billion and $524 billion, more than double Ukraine's pre-war GDP. These numbers highlight not only the unprecedented level of destruction but also the immense effort needed for economic recovery. Overall, studies by financial institutions and research organizations paint a picture of extensive and complex devastation: a collapse in output, physical damage, structural dislocation, and increasing poverty, all of which emphasize the urgency and magnitude of Ukraine's reconstruction efforts.

2.2 The Synthetic Control Method (SCM) in Conflict Economics

Although evaluating infrastructure and GDP losses is important, it frequently overlooks a more profound economic issue: What is the true cost of war when considering the unrealized potential, such as lost investments, income, and productivity growth? To explore this, economists increasingly turn to the Synthetic Control Method (SCM), a causal inference technique that creates a data-driven counterfactual by contrasting the treated unit with a weighted combination of similar, unaffected units.

The foundational research conducted by Abadie and Gardeazabal (2003) applied SCM to the Basque Country, revealing that terrorism led to a roughly 10% decrease in regional GDP per capita when compared to a synthetic control made up of other Spanish regions. Abadie et al. (2015) expanded this method to examine German reunification, finding that West Germany's GDP per capita was 8% lower than its synthetic equivalent annually from 1990 to 2003. These pivotal studies validated SCM's effectiveness in assessing the effects of distinct, single-case policy interventions. Furthermore, the evaluation of California's tobacco tax alongside prison realignment policies exemplifies SCM's versatility across areas such as health economics and criminal justice policy (Abadie, Diamond, & Hainmueller, 2010).

In addition to exploring case studies on crises or reforms, SCM has been employed to analyze large-scale integration processes. A notable example is Grassi's (2024) study on the "EU Miracle," which applied SCM to the 2004 EU enlargement. The findings indicated that by 2019, GDP per capita in the ten new member states (EU-2004) was 32% higher than their synthetic control, suggesting that EU accession contributed to nearly half of their income growth since joining. The primary driver of this growth was total factor productivity (TFP), with notable impacts from capital and labor; however, there was a lag in the convergence of productivity and efficiency. Various sensitivity checks, including placebo tests and alternative donor pools, validated the robustness of this outcome. This example illustrates SCM's effectiveness in highlighting the long-term macroeconomic benefits of structural political alignment, a crucial consideration for Ukraine.

In the Ukrainian context, SCM has been increasingly nuanced to measure the effects of conflict. One significant early study is Bluszcz and Valente's (2020) work, *The Economic Costs of Hybrid Wars: The Case of Ukraine*. They applied SCM to assess the causal impact of the Donbas conflict on Ukraine's GDP per capita from 2013 to 2017, revealing an average decline of 15.1%, or $1,439 (in 2011 PPP). At the subnational level, they observed severe reductions in gross regional product (GRP), with drops of 42% in Donetsk and 52% in Luhansk. Their donor pool, which included Moldova, Armenia, Bulgaria, and Slovenia, was confirmed through placebo and leave-one-out tests. The study highlighted mechanisms such as trade collapse, physical destruction, investment paralysis, and political instability. This research is notable for providing both national and regional SCM-based estimates, thereby emphasizing the detailed and systemic impacts of hybrid conflict.

Recently, SCM has been utilized to support broader discussions regarding economic damage and reparations. The HKA report, "*A Commentary on Potential Reparations Claims Arising from the Russia-Ukraine Conflict*," develops a synthetic model of Ukraine using various Eastern European comparators to assess cumulative GDP losses from 2014 to 2023. It estimates that Ukraine has lost around $1.57 trillion in output over the decade, with $323 billion lost in 2022 alone—the year marked by Russia's full-scale invasion (Williams, Flower, and Prantyuk, 2024). In contrast to conventional bottom-up accounting methods that concentrate on physical damage or lost revenues, this top-down SCM framework encapsulates overall output loss. The report also explores how these estimates could influence international reparations frameworks, including initiatives like the Register of Damage for Ukraine (RD4U), and makes relevant comparisons to the UN Compensation Commission following the Gulf War.

Other applications of SCM in the Ukrainian context have focused on more specific areas. For instance, Audretsch et al. (2023) analyzed the effects of the war on entrepreneurship, revealing a 15–20% decline in self-employment and SME activity compared to a synthetic control. However, these studies remain limited to particu5ar sectors. In contrast, this thesis employs SCM at the national macroeconomic level, constructing a synthetic Ukraine based on researched data and articles to estimate the hypothetical GDP trajectory without the war. This broader perspective establishes a foundation for strategic recovery planning.

2.3 Input–Output (IO) Modeling and Economic Recovery

The second primary methodology used in this thesis is Input–Output (IO) modeling, first introduced by Wassily Leontief in the 1930s. This Nobel Prize-winning framework outlines the structural relationships between various sectors in an economy. The IO model facilitates the simulation of how alterations in final demand within one sector ripple through both upstream and downstream industries. A key element of this method is the Leontief inverse matrix (Appendix, p. 57), which calculates the input-output production coefficients that represent the relationships between economic sectors. This technique enables analysts to track economic interconnections and measure both the direct and indirect impacts of sector-specific changes, making it especially useful for simulating economic disruptions caused by war (Belhaj, 2025).

Input-Output (IO) models are now a key tool for assessing economic impact, particularly in planning following disasters and conflicts. For example, in the U.S., the Bureau of Economic Analysis uses IO-based regional multipliers, such as RIMS-II, to evaluate how federal infrastructure investments affect local economies. Researchers, including Santos (2006) and Haimes and Jiang (2001), have evolved IO modeling into dynamic and "inoperability" frameworks to account for time-sensitive shocks, paths to recovery, and vulnerabilities within systems.

Recent studies underscore the significance of input-output (IO) modeling in evaluating Ukraine's wartime economy. The 2023 research titled "*War resilience of Ukraine's industries: An interdependent input–output analysis* " employs a national IO model to evaluate which sectors were able to maintain their operational capacity despite war-related challenges. The authors model the direct impacts from production constraints and infrastructure damage, along with the indirect spillover effects that affect supply chains. Their findings indicate that while the agriculture, food processing, and logistics sectors exhibited relative resilience, major industrial sectors like metallurgy, machinery, and chemicals faced considerable disruptions. Since these upstream sectors provide critical inputs for other industries, their decline led to intensified multiplier effects throughout the economy (Kovalchuk, Kharabsheh, & Santos, 2023). The study recommends that stabilizing a few key sectors could bolster overall economic coherence, offering valuable insights for the recovery scenarios discussed in this thesis. Thus, IO models function as both diagnostic instruments and prescriptive frameworks, identifying priority areas for policy interventions during times of crisis and reconstruction.

The commentary by HKA (2024) further highlights the relevance of IO in postwar economic planning, building on SCM-based GDP loss estimates with insights on macroeconomic modeling for recovery strategies. While the primary focus of the study is on SCM to assess Ukraine's total GDP loss, estimated at $1.57 trillion from 2014 to 2023, it also emphasizes the need to combine overarching macroeconomic losses with recovery simulations. Consequently, IO models can be strategically employed to bridge this gap by converting national output goals (such as restoring synthetic GDP) into practical recovery plans at the sector level. The HKA commentary underscores that reconciling systemic and detailed damage will be crucial for establishing postwar restitution frameworks and effectively directing international aid.

The IO literature highlights both the theoretical validity and practical applicability of this approach in conflict recovery scenarios. It allows planners to simulate physical damage spillovers, identify sectoral multipliers, and determine reconstruction investments, enabling them to go beyond mere headline losses and understand the structural pathways involved in economic recovery. This thesis builds on that work by incorporating a synthetic counterfactual GDP trajectory—derived through SCM—into the IO model, transforming a diagnostic tool into a proactive planning resource. This integration illustrates how SCM and IO can together provide a comprehensive understanding of what was lost and the potential for restoration.

2.4 Novel Contributions of Thesis

This thesis enhances the existing literature by introducing a policy-relevant framework that connects macroeconomic damage assessments to sector-specific recovery strategies, specifically designed for Ukraine's post-conflict situation. It achieves this through two primary innovations: a tailored Synthetic Control Method and its conjunction with an Input–Output simulation framework. The first innovation involves creating a credible synthetic version of Ukraine using a meticulously selected donor pool from regional peers. This approach enhances the precision of the counterfactual estimate, resulting in a significant GDP gap of ₴325.6 billion by 2021, which acts as a quantitative benchmark for recovery. The second aspect is the incorporation of this SCM-derived gap into a detailed IO model. The combined method not only quantifies economic losses but also simulates potential recovery through targeted demand injections.

The primary aim of this thesis is not to dictate a singular solution but to provide a flexible, data-informed framework for recovery planning. The SCM–IO framework serves as a customizable tool that policymakers can adjust to evolving circumstances, linking overarching macroeconomic objectives with targeted sectoral strategies. This study will demonstrate how to effectively transform the outputs of SCM for application in IO.

Chapter 3: Historical Context

3.1 Historical Economic Inheritance (1991–2013)

To understand Ukraine's economic trajectory, one must look beyond a simple chronological narrative; it requires recognizing the country's intricate structure, institutional inconsistencies, and geopolitical instability. Traditional comparative or econometric methods typically rely on stable peer grouping, uniform policy frameworks, or consistent shocks—all of which contradict Ukraine's case. Consequently, this chapter provides historical and structural insights to illustrate why conventional statistical tools are inadequate for assessing Ukraine's economic performance post-conflict. In contrast, the Synthetic Control Method is designed for scenarios without a natural control group. Its ability to create a counterfactual using a weighted mix of various comparison units makes it ideally suited for Ukraine, where regional differences, uneven shocks, and political disruptions undermine the viability of direct comparisons. The following sections outline Ukraine's economic journey from independence to the present, laying the empirical groundwork for utilizing SCM and analyzing the upcoming results.

After gaining independence in 1991, Ukraine faced a major economic shock. The transition from a planned economy throughout the 1990s involved hyperinflation, the breakdown of trade networks, and a reduction in output to less than 50% of Soviet-era levels (Åslund, 2009). A significant challenge occurred in 1998 when Russia, Ukraine's largest trade partner and previous metropole, failed to meet its sovereign debt obligations. Nevertheless, Ukraine avoided a financial crisis, signifying a preliminary divergence in economic performance (Aslund, 1999). From 2000 to 2008, Ukraine enjoyed a prolonged growth phase, fueled by industrial exports—especially metals and chemicals—as well as favorable commodity prices and an increase in domestic credit. The Orange Revolution in 2004 unsettled the government, and shortly thereafter, the global financial crisis of 2008 caused a considerable downturn, with GDP contracting by 15% in 2009 (Kuzio, 2009). The subsequent recovery was impeded by ongoing political instability. After the 2010 elections, a move towards centralization and cronyism undid many of the democratic reforms achieved post-Orange Revolution. Institutional integrity suffered, and economic policymaking became more opaque and influenced by clientelist practices. By the early

2010s, Ukraine remained susceptible to external pressures, heavily relying on commodity exports and facing institutional weaknesses (Kuzio, 2012).

3.2 The 2014: War and Economic Collapse

The Euromaidan protests from 2013 to 2014 were ignited by the government's abrupt rejection of an EU association agreement, escalating into a national crisis. State responses, including force against demonstrators, resulted in regime change and the rise of a pro-European political coalition. In reaction, Russia annexed Crimea and instigated violence in the Donbas region. These events led to immediate and severe economic repercussions. Donetsk and Luhansk—two industrialized areas—experienced significant disruptions in coal mining, steel production, and manufacturing supply chains. The loss of Crimea additionally impacted tourism, agriculture, and naval infrastructure. Consequently, GDP fell by 6.6% in 2014 and a further 9.8% in 2015 (IMF, 2024). The economy faced capital flight, sharp depreciation, failures in the banking sector, and rising inflation. By 2016, Ukraine’s nominal GDP had dropped to less than half its 2013 level in U.S. dollar terms (IMF, 2024). Domestic capital reserves were depleted, leading to forced consolidation within the banking system. Nevertheless, civil society mobilization and emergency aid from international institutions allowed for some degree of stabilization.

3.3 A Fragile Recovery (2016–2021)

From 2016 to 2021, Ukraine saw a gradual recovery. Despite ongoing low-intensity conflict in the Donbas, the economy exhibited stability, with GDP growth averaging between 2% and 3.5% from 2016 to 2019. This growth was supported by structural reforms, IMF-backed initiatives, and a rise in IT service exports. By 2021, agricultural production thrived, achieving record grain harvests and strengthening Ukraine’s position in the global food market. Reforms in fiscal decentralization improved local governance and optimized public investment allocation. By 2018, GDP had rebounded to around 80% of its 2008 figures. However, the economy still lagged behind regional peers like Poland and Romania, which experienced faster growth during this period. Per capita income remained among the lowest in Europe, underscoring ongoing institutional barriers, underinvestment, and unresolved structural issues. The economic challenges from the 2014 crisis persisted, particularly impacting manufacturing and export-oriented sectors. Nonetheless, by 2021, Ukraine had exceeded its 2013 nominal GDP (Poluschkin, 2022).

3.4 The 2022 Invasion and Economic Freefall

On February 24, 2022, Russia initiated a full-scale invasion of Ukraine, significantly broadening the scope and strategic ambitions of the conflict. The economic fallout was immediate and drastic. In 2022, Ukraine's real GDP plummeted by 29.1%—a decline rarely seen outside of civil wars or profound systemic failures (National Bank of Ukraine, 2023). Key industrial regions like Donbas, Zaporizhzhia, and parts of Kharkiv became battlegrounds, with their infrastructure and production capabilities destroyed or captured. The metallurgical sector was heavily impacted: steel output fell by over 70%, as crucial facilities like Azovstal in Mariupol ceased operations. Energy infrastructure endured relentless assaults, leading to rolling blackouts and halting production in various industries. Blockades in Black Sea ports halted the majority of maritime exports, causing a collapse in agricultural shipments. Grain production dropped by around 40% compared to 2021 (Council of the European Union, 2023).

The service sector also experienced significant disruption due to mass displacement, uncertainty, and logistical failures. Retail, logistics, education, and tourism were heavily impacted. By early 2023, one-third of the population had been displaced, either internally or abroad. The exodus of professionals and workers further stressed the labor market. Damage to infrastructure, including roads, power grids, schools, and hospitals, was estimated to exceed $524 billion by 2025 (World Bank, 2024). Even with a theoretical ceasefire, productive capacity remains substantially hindered.

3.5 Summary: Measuring the Output Gap

By 2023, Ukraine faced an economic reality where two decades of development gains had largely vanished. Despite this devastation, resilience emerged: businesses relocated westward, new logistics corridors were established through EU routes, and the IT sector swiftly adapted to remote operations. With continued international assistance, macroeconomic stability was carefully maintained, and forecasts projected modest growth of 2–3% for 2023 (Kalan, 2024). However, this rebound occurred from a significantly reduced base and remained far below any pre-war trajectory. This context underscores the central premise of this thesis: that a measurable gap now exists between Ukraine's actual and potential economic trajectory. The SCM method, applied in the next chapter, provides a rigorous way to estimate the lost output due to conflict by comparing Ukraine to a synthetic benchmark constructed from peer economies. This output gap, once identified, becomes the foundation for simulating sectoral recovery strategies using the IO model.

In short, Ukraine enters the post-war period not only needing to replace destroyed capacity, but also to recover from a prolonged loss of growth. The path forward is not simply reconstruction, but transformation: rebuilding institutions, modernizing economic structures, and targeting recovery investments to close the widening development gap. The following chapters present the methodological tools used to estimate this gap and to evaluate how different recovery strategies might perform in bridging it.

Chapter 4: Data & Methodology

To address the research question, this thesis employs a two-stage analytical framework that integrates the Synthetic Control Method (SCM) with a reverse-engineered Input–Output (IO) model. The SCM is used to construct a counterfactual trajectory of Ukraine's economy in the absence of conflict, quantifying the output loss attributable to war. This estimated gap then serves as the target in the IO model, which simulates alternative recovery strategies by calculating the sector-specific demand required to restore lost output based on Ukraine's 2021 intersectoral structure. By linking macro-level causal inference with structural recovery modeling, this approach provides a practical tool for evaluating reconstruction scenarios.

4.1 Data Used for SCM and IO

The data used for the SCM analysis in this study are sourced exclusively from the World Bank to ensure consistency, as different analytical platforms often rely on varying assumptions, as illustrated by the discrepancy in Ukraine's 2021 population estimates, with the World Bank reporting 44.3 million and the IMF reporting only 41.5 million. Since population figures significantly impact GDP per capita (PPP) and other derived indicators, relying on a single, interconnected data source is crucial for maintaining the integrity of the results and ensuring compatibility with input–output analysis. For the second part of the research, we utilized the official 2021 Input–Output table published by the State Statistics Service of Ukraine.

4.2 Synthetic Control Method

The Synthetic Control Method (SCM) is a causal inference technique that constructs a weighted combination of control units to simulate the counterfactual path of a treated unit without the intervention.

4.2.1 SCM Theoretical base

According to Abadie and Gardeazabal (2003), SCM is a weighted combination of comparable units, referred to as donors, designed to serve as a synthetic proxy for treatment. This method closely mirrors the performance of treatment prior to the intervention and provides an estimate of how treatment would have evolved afterwards had the intervention not occurred. In this thesis, SCM is employed to construct a counterfactual scenario for Ukraine's output variable, *GDP per capita (PPP)*, in the absence of war, by creating a weighted combination of regional countries (donors) that collectively resemble Ukraine before the conflict. The divergence between Ukraine's actual post-conflict economic trajectory and that of a synthetic one is interpreted as the causal impact of war on Ukraine's GDP per capita (PPP), assuming that no other unit experienced the same treatment[2].

The method proceeds in two stages. First, it determines the optimal weights assigned to each donor country, with the objective of closely matching Ukraine's pre-treatment characteristics. Suppose we observe $j + 1$ countries over T time periods, where country $j = 1$ (Ukraine) is exposed to a treatment (the war) after time T_0 (2014), and countries $j \ldots, j + 1$ serve as controls. Additionally, let $X_1 \in \mathbb{R}^k$ be a vector of pre-treatment averages of predictor variables for Ukraine (such as GNI per capita, FDI inflows, sectoral shares, trade openness, etc.), and $X_0 \in \mathbb{R}^{kJ}$ be the corresponding matrix for the donor countries. The SCM algorithm solves the following optimization problem:

$$min\_W \ (X_1 - X_0W)^{\mathrm{t}} V \ (X_1 - X_0W)$$

subject to: $w_j \geq 0 \ and \ \sum_{j=2}^{J+1} w_j = 1$

Here, W is a vector of weights applied to the control units, and V is a diagonal matrix that captures the relative importance of each predictor in minimizing the pre-treatment distance between Ukraine and the synthetic unit. This step ensures that the synthetic Ukraine is constructed to be as similar as possible to actual Ukraine before the intervention. In the second stage, the optimal weights w_j are used to generate the synthetic outcome trajectory. Let Y_{jt} denote the GDP per capita (PPP) for country j at time t, and Y_1t be the actual value for Ukraine. The synthetic control's outcome is defined as:

$$Y_{synthetic}, t = \sum_{j=2}^{J+1} w_j \cdot Y_{jt}$$

[2] The SCM is **not** a regression model. It does not estimate treatment effects through parametric models; instead, it builds a weighted combination of untreated units to replicate the treated unit's pre-treatment trajectory, without assuming a functional form or relying on regression coefficients.

In this study, the difference between Ukraine's actual GDP and that of the synthetic control in the post-treatment period *($t \geq T_0$)* is called the gap, the causal effect of intervention:

$$Gap_t = Y_{1t} - Y_{synthetic}, t$$

SCM offers key advantages, including an objective approach to choosing comparison units, the capacity to adjust for changing unobserved confounders over time, and the versatility to handle assumptions like parallel trends when they may not be valid. By empirically recreating Ukraine's pre-war path and addressing structural shifts and events such as the 2008 financial crisis, SCM establishes a credible and clear counterfactual. This counterfactual acts as a benchmark for assessing the economic impacts of the war and aids in the second-stage analysis of sectoral recovery through input–output modeling (Abadie, Diamond, & Hainmueller, 2010).

4.2.2 Methodological Procedure

As previously mentioned, implementing SCM involves several steps. Ukraine is the treated unit, and the "treatment" is the outbreak of conflict. We take 2014 as the starting point of the intervention, as it marks the beginning of hostilities: effectively, 2014-2023 is the post-intervention period in our analysis, which includes the major escalation in 2022 as part of the ongoing conflict impact. The pre-intervention period consists of the years before 2014, during which we have data and where Ukraine faced other events, though nothing on the scale of total warfare. For our baseline analysis, we use annual data from 1996 through 2013 as the training period in which synthetic control is constructed (earlier years in the 1990s were excluded due to extreme volatility and structural breaks after the Soviet Union's collapse).

Next, we identify a donor pool comprising 18 countries (Figure 4.1), which serve as the candidate units for constructing the synthetic Ukraine. This pool includes nations from the same economic region as pre-2014 Ukraine that were not impacted by Russian aggression or similar military disruptions. We select regional countries that are close enough peers to Ukraine in terms of development and economic structure, while excluding those directly affected by combat post-2014, to prevent contamination from spillover effects. The donor pool features countries like Poland, Romania, Bulgaria, Hungary, Slovakia, Czechia, and Croatia, among others. These nations experienced no warfare within their borders during the relevant timeframe and collectively represent a varied sample of transition economies and Eastern EU enlargements, some of which had growth trajectories reminiscent of Ukraine's path before 2014. By omitting Russia and Belarus, as principal actors in the war, we prevent inclusion of donors that are directly involved or economically linked to the conflict dynamics. This methodology aligns with earlier research, such as that of Williams, Flower, and Prantyuk (2024), which also selected Eastern European countries to create a synthetic Ukraine.

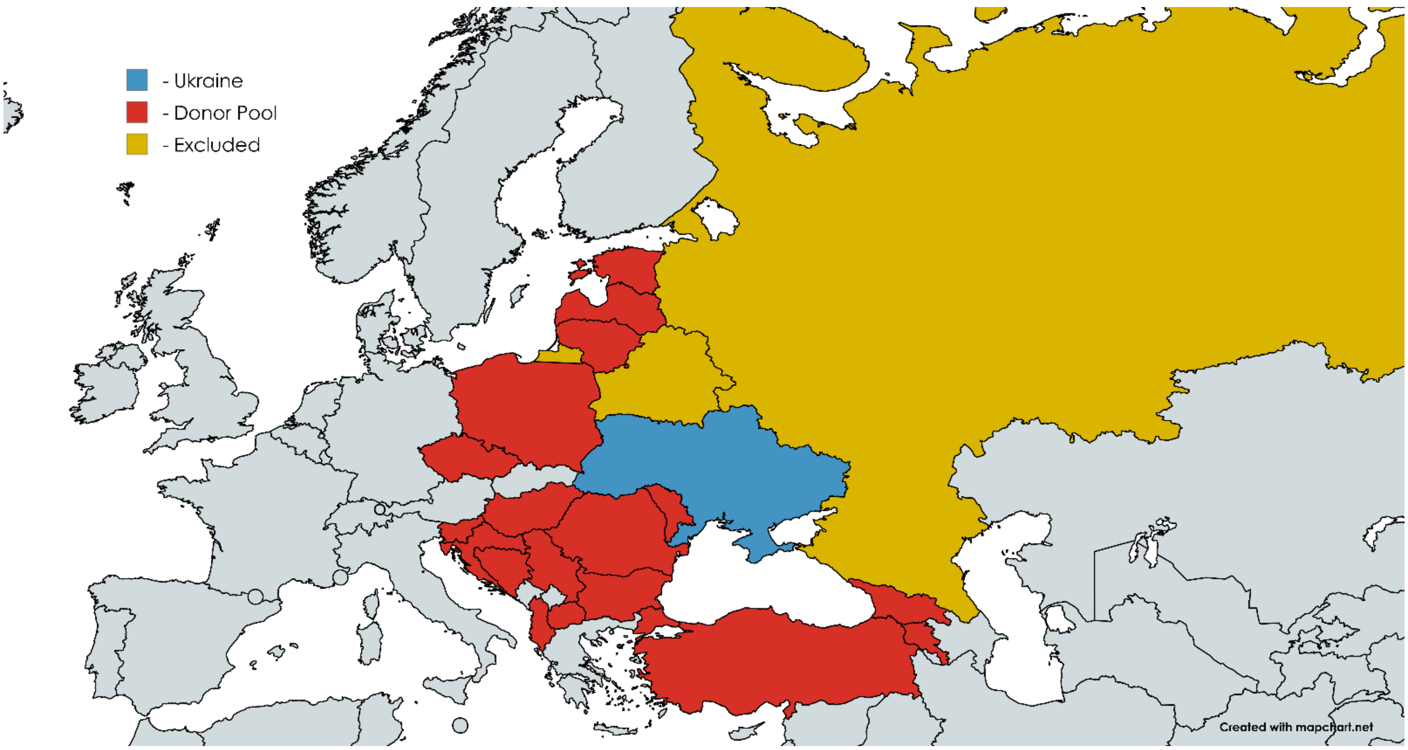


Figure 4.1. Donor Pool Composition for the Synthetic Control Model of Ukraine. *This map illustrates the regional donor pool used to construct the synthetic Ukraine in the SCM analysis. Ukraine is shown in blue, while the 18 selected donor countries are highlighted in red. Countries in yellow, including Russia and Belarus, were excluded due to their direct involvement in the conflict. Source: Author's own visualization using MapChart (https://www.mapchart.net/world.html)*

It's important to recognize that some countries in the donor pool have limited exposure to conflict; however, their inclusion is justified based on either the frozen nature of their disputes during the study period or the considerably smaller scale and localized nature of violence compared to the Russian aggression against Ukraine. For example, Georgia is part of the pool despite its 2008 war with Russia, which, although politically significant, resulted in fewer than 500 casualties and lasted only 16 days. Moldova is also included despite lacking control over Transnistria since 1992, as that conflict has effectively remained frozen. Armenia is included, despite its ongoing intermittent conflict over Nagorno-Karabakh, because notably, the fighting has not occurred on internationally recognized Armenian territory. Likewise, Serbia is part of the pool, despite its experiences with the 1999 NATO bombing and the separation of Montenegro in 2006, as both episodes are mostly political events in the broader context and did not lead to sustained conflict thereafter. North Macedonia, which experienced localized armed clashes with insurgents in the early 2000s, has since undergone a peaceful stabilization process, making it a valid comparator.

To ensure a credible estimation of Ukraine's counterfactual economic trajectory, the SCM relies on a carefully selected set of predictor variables that capture relevant macroeconomic and structural characteristics before the onset of conflict. The primary outcome variable is GDP per capita in purchasing power parity terms (PPP, current international dollars), which enables meaningful cross-country comparisons of living standards and output. We created a variable called GDP-GNI per capita (PPP) difference to track incoming private capital flows from abroad, thus replicating not only the level but also the trajectory of economic development.

Along with GDP metrics, a broad array of economic and structural indicators is incorporated into the predictor set. These include measures of international financial integration such as *foreign direct investment (FDI) net inflows* expressed both as a percentage of GDP and in current U.S. dollars, as well as the *current account balance*. Trade openness is captured through *net trade in goods and services* (BoP, current US$), *exports*, and *imports* as percentages of GDP. Sectoral composition is accounted for via *value added in agriculture, industry (including construction),* and *services*, all as shares of GDP. Domestic financial depth is proxied by indicators such as *domestic credit to the private sector by banks* (% of GDP) and *monetary sector credit to the private sector*. Additionally, the *PPP conversion factor (local currency unit per international dollar)* and the *GDP–GNI differential per capita in PPP* terms are included to capture variations in purchasing power and national income definitions. The variables were selected based on their theoretical relevance to economic performance and institutional comparability across the donor pool, ensuring that the synthetic control unit not only shares similar historical output trends but also reflects the economic structures.

4.2.3 Inference and Assumptions

The analysis includes placebo tests and a leave-one-out sensitivity check, both commonly used as detailed in the Literature Review chapter. In the placebo tests, each donor country is hypothetically treated as if it underwent the intervention in 2014, with a synthetic counterpart created from the remaining countries. This method allows us to determine whether significant GDP differences could occur by chance alone. The discovery that Ukraine's post-2014 gap is considerably larger than that of the placebo units supports a causal interpretation of the findings. To further verify the reliability of the synthetic control, we conduct a leave-one-out test by progressively excluding each donor country and re-estimating synthetic Ukraine. This process ensures that the results are not unduly reliant on any individual country in the donor pool. Collectively, these robustness checks affirm the stability and dependability of the SCM estimates. Notably, synthetic Ukraine still aligns with global economic trends—like the downturn in 2020 caused by the COVID-19 pandemic—showing that the counterfactual considers international shocks while isolating the specific impacts of war. All findings, inclusive of the estimated GDP gap and robustness diagnostics, are presented in Chapter 6.

It is essential to recognize the assumptions and limitations of the SCM approach within this context. SCM operates under the premise that there are no significant spillovers between the treated unit and the donors; here, we assume that the conflict in Ukraine did not majorly disrupt the economic trends of our donor nations (which remains reasonable for countries like Poland or Hungary up until 2022, although the 2022 invasion did result in some spillover effects across Europe—such as increased energy prices). Another key assumption is unit stability: absent the conflict, Ukraine's economy would have mirrored the collective patterns of the donors—an assumption that, while impossible to test, is grounded in Ukraine's previously similar regional trajectory before 2014. Lastly, like any model, SCM cannot capture every potential difference; there may be unobserved influences (e.g., political reforms, sector-specific factors) that could lead the synthetic counterpart to diverge from Ukraine's actual outcomes. Nevertheless, as a data-driven approach, SCM offers a clear and replicable method to assess the impact of the war, providing critical input (the magnitude of the GDP gap that needs to be addressed) for the subsequent part of our analysis.

4.3 Input-Output Framework and the Leontief Model

An Input-Output (IO) table systematically represents all inter-industry transactions within an economy for a specific year. Typically arranged as a matrix (in our case, 42 x 42 sectors), the columns indicate purchasing sectors, while the rows show supplying sectors. Each cell in the IO matrix displays the value of goods or services that a column industry buys from a row industry. Besides the intermediate flows between industries, the IO table features a final demand section (located at the top right) that reflects consumer spending, governmental expenditures, investments, and net exports for each sector's output. Additionally, it includes a value-added section, accounting for non-intermediate inputs such as wages, taxes minus subsidies, and profits. The fundamental premise of inter-industry flows in an IO table is that industries serve as both producers of output and consumers of inputs from others, establishing a network of dependencies. For instance, the steel industry might obtain energy from the utilities sector and ores from the mining sector, while providing steel as an input to the construction and machinery sectors. Hence, the IO framework illustrates how the output of one sector becomes an input for another, interlinking all sectors within a complex web of transactions.

4.3.1 Input-Output Theoretical base

According to the Encyclopedia of Social Measurement (2005), each element a_{ij} (cell) of matrix **A** represents the amount of input from sector *i* required to produce one unit of output in sector *j,* formally defined as:

$$a_{ij} = \frac{Z_{ij}}{X_j}$$

Where Z_{ij} is the monetary value of goods or services that sector j purchases from sector i, and X_j is the total output of sector j. The resulting coefficients reflect both the technological requirements of production and the strength of intersectoral economic linkages. These relationships are formalized in matrix notation, where **X** is the column vector of total sectoral output, **F** is the column vector of final demand, and **A** is the coefficient matrix. The foundational accounting identity of the input–output model is then expressed as:

$$X = A \cdot X + F$$

This equation states that the total output of each sector is split between intermediate demand **A·X**, which includes the inputs required by all other sectors, and final demand **F**, which includes consumption, investment, government spending, and exports. Assuming the matrix (**I-A**) is non-singular, where **I** is the identity matrix matching the dimensions of the input coefficient matrix **A,** requires that the economic structure is not degenerate or fully dependent on imports, we can solve for the total output vector as a function of final demand:

$$X = (I - A)^{-1} \cdot F$$

This formulation is known as the *Leontief inverse*, named after its founder Wassily Leontief. The matrix $(I - A)^{-1}$ reflects both the *direct* and *indirect* output requirements across all sectors needed to meet one unit of final demand in a specific sector. In other words, it captures the complete cascade of production effects: an increase in demand for goods in one sector stimulates output not only in that sector but also in all sectors supplying intermediate goods, and so on, through multiple rounds of input demands (Boulding, 1942).

4.3.2 Modified "Flipped" IO Approach for Output Targets

While the traditional Leontief input–output model estimates total output as a response to a given vector of final demand, this thesis reverses that logic. In the context of post-war reconstruction in Ukraine, the primary policy question is not "what output follows from new demand?" but rather "what demand is required to reach an output target to bridge the gap?" That is, we are not simulating the effects of a hypothetical fiscal stimulus. Instead, we begin with a targeted output level corresponding to the GDP gap estimated via the SCM and seek to determine the scale and sectoral composition of final demand necessary to close that gap. Assuming that the desired output vector **X** is known based on SCM results, we solve for the final demand **F**:

$$F = (I - A) \cdot X$$

This formulation yields a vector where each element F_i represents the total amount of final demand (whether from households, government spending, investment, or net trade) required to support an output level X_i in sector i. Importantly, this inversion does not represent a modification of the Leontief model itself but rather a reorientation in its use: from output-determined-by-demand to demand-required-for-output.

In practical terms, this "flipped" approach allows us to estimate how much and where reconstruction investments or demand-side interventions need to be allocated. For instance, if Ukraine seeks to restore a certain level of total output which is equivalent to the shortfall estimated through SCM, this method allows us to calculate how much final demand must be directed into agriculture, industry, or services to achieve that output, while accounting for the inter-industry dependencies embedded in the technical coefficients matrix **A**.

4.4 Intermezzo: Converting SCM Results for the IO model

The methodology consists of five sequential steps that combine macroeconomic gap estimation with the IO model to calculate the required final demand injection. Below, we detail each step of the process.

4.4.1 Estimating the GDP per capita PPP gap

The first step is to quantify the overall economic shortfall that the recovery efforts aim to overcome, utilizing the SCM to estimate Ukraine's GDP per capita (PPP). By comparing this counterfactual GDP per capita to the actual GDP per capita, we derive an estimate of the per capita GDP gap. This gap indicates how much poorer the average person in Ukraine is compared to the scenario without the crisis. It is then scaled up to the national level by multiplying by Ukraine's population of 44,298,640 (World Bank, 2021). The result of this calculation is an estimated total GDP gap (PPP) of $44,608,730,480. In other words, according to the analysis, the Ukrainian economy requires an additional $44.6 billion to its total GDP PPP of $746.47B (~6% of additional output) to catch up to its hypothetical trajectory. This forms the basis for the subsequent calculations.

4.4.2 Converting the GDP gap into local currency terms

Input-Output analysis is conducted in local currency, so the IO tables for Ukraine are denominated in Hryvnia. Therefore, step 2 is to convert the GDP gap from current dollars (in purchasing power parity, PPP) into nominal UAH. We utilize the World Bank 2021 PPP conversion factor for Ukraine, which is approximately 7.3 UAH per international dollar. This factor reflects the ratio of local currency to PPP-adjusted dollars for that year, capturing differences in price levels between Ukraine and the USA. By multiplying the PPP GDP gap ($44.6 billion) by 7.3, we convert the gap into nominal terms. This results in a GDP gap of roughly 325.6 billion UAH that Ukraine would need to add to its economy to achieve the targeted output level. The resulting nominal GDP gap accounts for approximately 6% of the 2021 IO's Total Gross Value Added, supporting the conversion factor as a reliable tool.

4.4.3 Computing Sectoral Value Added (VA) Ratios

With the GDP gap now expressed in local currency, the analysis progresses to allocate it among the selected sectors based on specific scenarios to estimate the output needed to eliminate the gap. Before proceeding, we need to convert the nominal GDP gap into the appropriate output for each sector. This is done by utilizing the Value Added (VA) ratio for each sector, indicating the part of a sector's overall output that directly contributes to GDP. Mathematically, for sector *i*:

$$VA_{ratio_i} = \frac{Gross\ Value\ Added_i}{Total\ Output_i}$$

Gross Value Added (GVA) of a sector represents the difference between its total production and intermediate inputs, effectively quantifying the sector's direct contribution to GDP value added. For instance, if the agriculture, forestry, and fishing sector produces ₴1,396B in output while consuming ₴803.4B in inputs, its value added is ₴593.3B, resulting in a VA ratio of 0.4248 (IO, 2021). These ratios enable the conversion of a target GDP increase, in this case, value added, into the *targeted output* from each sector. A sector with a lower VA ratio must generate higher output to achieve a specific increase in value added, making the VA ratio a scaling factor in the IO model. For example, targeting ₴50 billion in Gross Value Added from a sector with a VA ratio of 0.5 necessitates ₴100 billion in output. In this thesis, VA ratios are calculated from Ukraine's 2021 IO tables for all 42 sectors and can be found in the Appendix (p. 55). These ratios are then utilized in the subsequent step to translate a sectoral allocation of the GDP gap into output targets. This step ensures that the requirements for intermediate inputs are considered during the recovery planning process.

4.4.4 Allocating the GDP gap to sectors and calculating the required output

The next step involves distributing the *targeted output* across individual sectors based on alternative recovery scenarios. These scenarios represent strategic priorities, such as focusing reconstruction efforts on infrastructure, industry, or agriculture, rather than assuming a uniform allocation across the economy. In composition, every sector is arbitrarily assigned a weight w_i, representing the share of the targeted output:

$$w_i \geq 0; \sum_i w_i = 1$$

In other words, the portion of the GDP gap allocated to sector *i* is then:

$$\Delta GVA_i = w_i * GDP\ Nominal\ Gap$$

This value represents the additional gross value added (GVA) that sector *i* must generate under the given recovery scenario. To determine how much targeted output is needed in each sector to meet this value-added target, we use the VA ratios computed in Step 4.4.3:

$$\Delta X_i = \frac{\Delta GVA_i}{VA_{ratio_i}}$$

where ΔX_i is the required output share of a particular sector needed to generate a targeted value added ΔGVA_i. This adjustment accounts for the role of intermediate inputs in production: most sectors require more than ₴1 in total output to generate ₴1 of new GDP. Assume a scenario of sectors *A* and *B*. If sector *A* has a VA ratio of 0.2 and receives a weight (w_A) of 0.5 while sector *B* has a VA ratio of 0.4 and a weight (w_B) of 0.5, then a targeted output equals: $\Delta X_A * w_A + \Delta X_B * w_B = \frac{325.6\text{B}*0{,}5}{0.2} + \frac{325.6B*0.5}{0.4} = 814\text{B} + 407\text{B} = ₴1{,}221\text{B}$

Meaning to bridge a gap of ₴325.6B, the economy will need to produce ₴1,221B more gross output in those two sectors. Applying this procedure across all sectors of the scenario yields a new output vector, denoted *X**, which contains the gross output increases required in each sector to bridge the ₴325.6 billion GDP gap. This vector serves as the input for the final step of the methodology, which computes the final demand injections.

4.4.5 Deriving the required final demand injection (reversed Leontief calculation).

In the final step of the methodology, we translate the sectoral output targets *X** (from the previous step) into the corresponding levels of final demand required to achieve them. This is done using the rearranged Leontief framework $[F = (I - A) * X]$. In our case, the target output vector X^* represents the required level of gross output across sectors necessary to close Ukraine's GDP gap. Plugging this vector into the formula, we obtain the final demand:

$$F^* = (I - A)X^*$$

This matrix operation subtracts from the total output the portion consumed as intermediate inputs (i.e., goods and services used in the production processes of other sectors). The resulting vector F^* tells us how much *final demand* from consumption, investment, or government spending must be injected into each sector to support the recovery. Each element F^* in this vector represents the additional *final demand* for sector i's output required to trigger the targeted increase in production. Summing across all sectors gives the *total final demand injection* necessary to bridge the GDP shortfall of ₴325.6 billion. This approach ensures internal consistency because the IO matrix **A** captures how outputs from one sector feed into others as intermediate inputs, and the estimated final demand vector accounts for the ripple effects throughout the economy. For example, increasing output in construction also increases demand for steel, cement, transport, and other upstream sectors – all of which are factored into F^* by the definition of Leontief (Boulding, 1942).

In practical terms, this step tackles a vital policy question: what additional spending is necessary, and in which sectors, to bridge Ukraine's wartime GDP gap? Potential sources of final demand might encompass public investment, infrastructure enhancement, private consumption, or export development efforts, like revitalizing the grain trade. It's important to note that this analysis recognizes the necessity of addressing supply constraints. Elements such as labor availability, capital stock, and infrastructure capacity will significantly influence the feasibility of various recovery scenarios. While understanding these constraints is crucial for realistic planning, a detailed analysis would require a comprehensive framework that extends beyond this study's scope. Nevertheless, this step is instrumental in converting macroeconomic output objectives into specific demand-side needs, providing a quantitative guide for the scale and allocation of stimulus required to close the output gap, grounded in the structural relationships evidenced by Ukraine's 2021 input-output matrix.

Chapter 5: Scenario Design

This chapter outlines a structured approach to model Ukraine's recovery prospects by developing various counterfactual recovery scenarios based on differing strategic priorities. Each scenario projects a unique distribution of economic recovery funding across sectors while aiming for the same macroeconomic goal: closing the estimated ₴325 billion GDP gap identified through the SCM–IO framework. The design of these scenarios and the allocation of weights are guided by two fundamental principles: sectoral interconnectivity and empirical plausibility. The selection of sectors is rooted in their historical structure and functional significance, ensuring that only those with proven importance to Ukraine's economic system are prioritized as strategic leaders. Weights for each sector are assigned based on their historical gross output shares, avoiding arbitrary inflation of sectors just due to high value-added (VA) ratios. This methodology upholds economic realism and mitigates disproportionate scaling of highly specialized industries. Consequently, the scenarios present feasible policy options and serve as a foundation for assessing the viability and effectiveness of various recovery strategies. Following this, four distinct scenarios are introduced: Infrastructure-Led, Industrial Revitalization, Agricultural, and Balanced, with the sectoral weights outlined in the Appendix (p.58-59).

5.1 Infrastructure-Led Recover

The Infrastructure-Led Recovery scenario models a post-war rebound in Ukraine that is primarily driven by large-scale investment in physical infrastructure, including roads, utilities, logistics, and related support services. This strategy is grounded in both economic logic and the recovery literature cited earlier in the thesis, which emphasizes infrastructure as a backbone of economy and a catalyst for activating intersectoral linkages.

Weight allocations are designed with caution: rather than maximizing technical efficiency (e.g., by choosing only sectors with the highest VA ratios), the approach accounts for real economic composition, sectoral output sizes, and systemic necessity. Infrastructure recovery is not optional—it is essential for the operation of functional urban life and virtually all other sectors. Towns and cities require roads, water, energy, and telecommunications regardless of demographic shifts or economic contraction. As such, infrastructure demand is relatively inelastic and must be restored to baseline levels even before broader economic activity resumes.

A significant portion of the ₴325 billion GDP gap is thus allocated to infrastructure-relevant sectors, with *Construction* (0.35) as the anchor, followed by key enablers: *Electricity and Gas* (0.2), Transport and Warehousing (0.2), Water Supply (0.05), and *Telecommunications* (0.05). Supporting sectors like *Engineering*, *Metal Fabrication*, and *Minerals* are also included to capture upstream material and service demands.

This distribution ensures that the recovery stimulus reflects both functional necessity and economic realism. Beyond the direct impact, the infrastructure-led path generates indirect demand through supply chains. Demand for cement, metal, transportation services, and technical supervision stimulates a wide range of supporting industries, acting as both a stabilizer and a multiplier. Essentially, this scenario underscores that infrastructure investment is not only a fiscal stimulus but also a structural prerequisite for any meaningful recovery.

5.2 Industrial Revitalization

The Industrial Revitalization scenario envisions Ukraine's post-war recovery through a renewed focus on manufacturing and heavy industry. This strategy draws on historical examples, particularly the Korean development model (Park, 1979), and current economic development literature, highlighting the essential role of industrial sectors in boosting productivity, generating jobs, and driving technological progress. The selected sectors are strategically important as they are crucial to Ukraine's current industrial landscape and closely connected to upstream and downstream supply chains. Sectoral weights are determined not only by their individual efficiency but also by their actual economic effects and interconnections, ensuring that recovery efforts align with structural realities and avoid an excessive focus on narrowly efficient areas.

This scenario channels a substantial portion of the ₴325 billion GDP gap into capital-intensive, value-added production sectors such as *basic metals* (0.25), *machinery and equipment* (0.15), and *chemical manufacturing* (0.1). These industries not only have strong backward linkages (e.g., requiring mining, energy, and transport) but also supply intermediate goods crucial for other sectors, such as construction, energy infrastructure, and agriculture. In this way, investment in industrial production yields compounding benefits across the economy.

5.3 Agricultural Recovery

The Agricultural Recovery scenario places Ukraine's economic renewal at the heart of the agri-food complex, which has long been viewed as one of the country's key advantages. Leveraging Ukraine's natural resources, rural workforce, and its historically vital role in global food supply chains, this strategy capitalizes on established strengths to promote both domestic stability and external revenue. The selection of sectors follows an integrated value chain approach—from farm production to processing, transport, and upstream supply industries—ensuring that recovery investments are productive, interconnected, and scalable. Importantly, sectors have been selected based on their economic roles within the agricultural ecosystem, as well as their statistical significance in national accounts. Weight assignments reflect not just theoretical returns but tangible contributions to Ukraine's economy, avoiding distortion from overstating sectors that solely exhibit high value-added ratios.

This scenario allocates the ₴325 billion GDP gap with a strong emphasis on *agriculture* (0.3), *food manufacturing* (0.2), and *transport and warehousing* (0.2), followed by supporting sectors such as *chemicals*, *textiles*, and *machinery*. These enable productivity improvements and trade facilitation. The following structure reflects a comprehensive development strategy grounded in food security, export strength, and regional revitalization. The integration of processing, logistics, and essential inputs ensures that recovery efforts create durable linkages across the economy.

5.4 Balanced Recovery

The Balanced Recovery scenario envisions a multi-sector strategy for Ukraine's economic rebound, designed to distribute recovery investments across a broad segment of the economy. This approach acknowledges that no single sector can drive sustainable growth alone, particularly in a complex post-conflict landscape. Instead, it targets a portfolio of interconnected industries—from agriculture and manufacturing to infrastructure and modern services—to establish a diversified and resilient foundation for long-term recovery. Sector selections are based on the thesis's literature review, highlighting systemic interconnectivity, economic relevance, and recovery scalability. The scenario prevents overconcentration by assigning weights not only according to value-added potential but also based on a sector's share of pre-war output and its role in supporting other sectors. This ensures the distribution avoids exaggerating gains from sectors with merely high technical multipliers.

The scenario's logic is twofold: first, to ensure that the recovery process encompasses every core area of economic life, and second, to shield the economy from sector-specific volatility. Notable allocations are made for *construction* (0.1) and *transport* (0.05), recognizing their enabling role for other industries. *Agriculture* (0.1) and the *manufacturing of food* (0.05), *textiles* (0.05), *chemicals* (0.05), *metals* (0.05), and others remain crucial due to their foundational importance in both domestic and export-oriented activities. Meanwhile, services such as *education* (0.05), *health* (0.05), *ICT* (0.05), and *public administration* (0.05) are strategically targeted for social stabilization and human capital development. It fosters broad-based economic revitalization, promotes inclusive growth across regions, and offers flexibility to adapt to external shocks and evolving global trends. Consequently, it serves as a pragmatic blueprint for recovery.

While all four scenarios aim to bridge the same ₴325 billion GDP gap, they reflect distinct priorities: Infrastructure-Led Recovery emphasizes foundational rebuilding; Industrial Revitalization focuses on reactivating high-value manufacturing; Agricultural Recovery leverages Ukraine's natural and export strengths; and Balanced Recovery allocates investment across sectors to foster resilience and inclusivity. These scenarios are not exhaustive policy prescriptions but practical illustrations of how the proposed methodology can be applied. Given that the core of this thesis is to develop a replicable template for recovery analysis, these examples demonstrate the framework's flexibility, usability, and relevance in real-world contexts.

Chapter 6: Results and Scenario Comparison

This chapter starts by discussing the results of the synthetic control analysis, which assesses the war's impact on Ukraine's GDP. Next, we analyze the outcomes of the input–output model simulations concerning the previously described reconstruction scenarios. Finally, we compare these scenarios with one another and the hypothetical no-war path to determine the extent of the "lost" output that can be regained in each case. Detailed data, tables, and graphs can be found in the Appendix section.

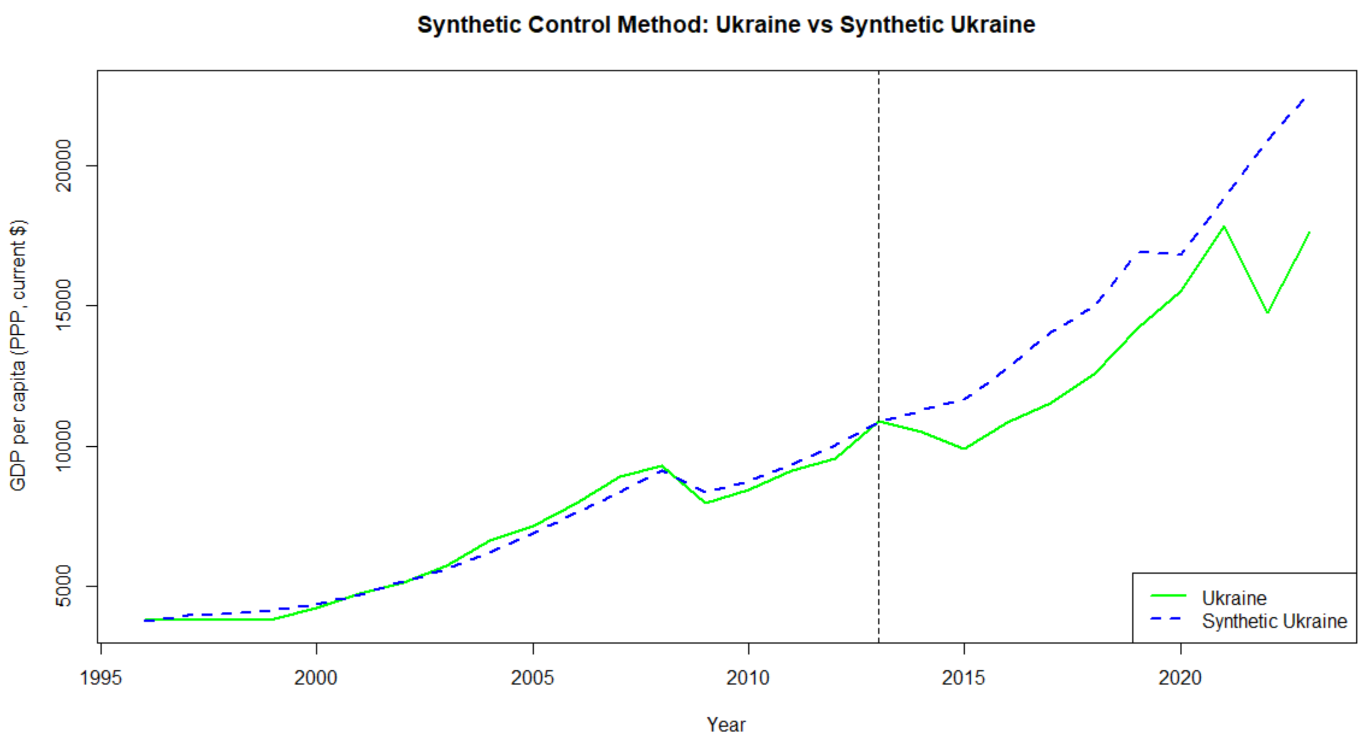


Figure 6.1. Ukrainian vs. a Synthetic Ukraine without conflict (GDP in PPP international dollars, 1996–2023)*. The dashed line ("Synthetic Ukraine") represents the estimated GDP path Ukraine would have followed had no war started in 2014, constructed via the synthetic control method. The green line shows Ukraine's actual GDP. The divergence after 2014 reflects the economic cost of conflict. Notably, the gap widens drastically in 2014–2015 (initial war impact) and again in 2022 (full-scale invasion), indicating the immense cumulative loss in output due to the war. Source: Author's calculation using SCM in R.*

6.1 SCM Findings

The synthetic control model successfully replicates Ukraine's GDP per capita (PPP, current international $) trajectory during the pre-intervention period (1996–2013), demonstrating a close fit between actual and synthetic values. As shown in Figure 6.1, the actual GDP per capita of Ukraine and the synthetic control move in near-parallel throughout this period, with minimal deviation. Considering that Ukraine's GDP per capita PPP started with $3,812 and grew to $10,904 in 2013 (Appendix, p.52), the strong alignment is quantified by a low pre-treatment root mean square error (RMSE) of 282.52, confirming the robustness of the donor pool construction and the validity of the counterfactual estimate. Beginning in 2014, Ukraine's actual GDP per capita diverged sharply from the synthetic trend. The gap expands over time, reflecting a significant and sustained negative impact of the 2014 conflict and subsequent instability on Ukraine's economic performance. By visual inspection and statistical evaluation, the post-2013 trajectory of the Ukrainian economy departs substantially from what would be expected in a no-conflict scenario, providing strong evidence of the war's detrimental long-term effect.

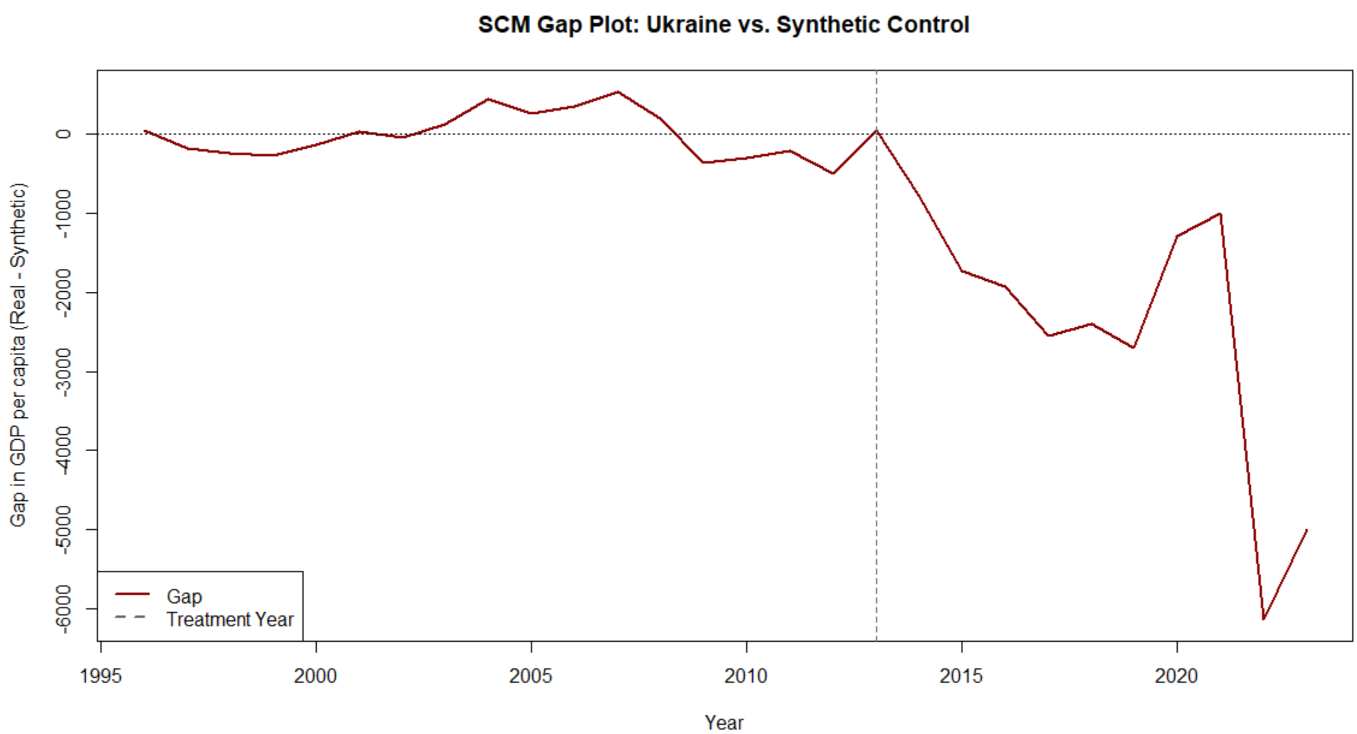


Figure 6.2. SCM Gap Plot: Ukraine vs. Synthetic Control (1996–2023). *This graph displays the estimated gap in GDP per capita between actual Ukraine and a synthetic Ukraine without conflict, constructed using the Synthetic Control Method. The solid red line reflects the difference between the real and the synthetic one, with values below zero indicating economic underperformance relative to the synthetic control. The dashed vertical line marks 2014, the onset of conflict. Post-2014, the gap widens substantially—first during the initial war years (2014–2015) and again sharply in 2022 following Russia's full-scale invasion—highlighting the severe and compounding economic losses attributable to the war. Source: Author's calculation using SCM in R.*

By 2021, Ukraine's actual GDP per capita was approximately $1,007 lower than that of its synthetic counterpart, marking a substantial shortfall from the counterfactual trajectory. This divergence is clearly visible in Figure 6.2, where Ukraine's actual GDP per capita line flattens and declines, while the synthetic control continues on a steady upward path. The $1,007 gap represents a significant economic loss, equivalent to roughly 6% of Ukraine's GDP per capita in that year, consistent with IMF (2024) findings of an average annual loss of around 8-9% during the pre-invasion period. When scaled to the national level using Ukraine's estimated 2021 population of 44.3 million, this per capita shortfall translates into an aggregate GDP (PPP) loss of approximately $44.6 billion (~6% of $746.47B). Using the 2021 World Bank PPP conversion factor of 7.3 UAH per USD, the nominal GDP gap amounts to around ₴325.6 billion. model.

In addition to the graphical evidence, the model's error diagnostics and donor composition further strengthen the credibility of the estimated treatment effect. The post-treatment root mean square error (RMSE)—which measures the deviation between Ukraine's actual and synthetic GDP per capita after 2013—is 3,036.33, compared to a pre-treatment RMSE of just 282.52. This leads to a post-/pre-treatment RMSE ratio of 10.75, indicating that the prediction error increased more than tenfold after the onset of the conflict. Such a significant rise in post-treatment error is consistent with a strong and lasting causal impact of the intervention, further validating the SCM estimate.

The creation of synthetic control also highlights important economic parallels. The three primary donor countries are Armenia, Romania, and Hungary, with assigned weights of 0.54, 0.35, and 0.10, respectively. This selection indicates that Armenia's post-Soviet, lower-middle-income development path closely mirrored Ukraine's pre-2013 economic trajectory, while Romania and Hungary contributed structural features typical of more advanced transitional economies. Collectively, these countries formed a weighted combination that effectively mirrored Ukraine's GDP per capita trend before treatment. The strong alignment observed during this pre-treatment phase, demonstrated by the low RMSE and near-zero bias, enhances trust in the counterfactual's validity. It supports the view that the expanding gap noted after 2013 represents the economic impact of the conflict rather than a modeling anomaly.

6.2 SCM Inference Checks

To confirm that the observed divergence between actual and synthetic Ukraine is statistically significant and not merely the result of random variation or model instability, the study conducted several inference and robustness checks. One of the approaches in synthetic control studies is the "in-time placebo" test, which applies the treatment artificially in an earlier period, when no intervention occurred, to examine whether the model would falsely detect an effect (Abadie, Diamond, & Hainmueller, 2015). However, in Ukraine's case, this method was not viable. As discussed in *Chapter 3*, the country's pre-2013 economic trajectory was marked by multiple structural shocks, including the 2004 Orange Revolution, the extremely harsh consequences of the 2008 global financial crisis, and significant policy reversals under a pro-Russian administration around 2010. These events caused real breaks in the economic trend, meaning a sufficiently stable pre-treatment period does not exist, while an in-time placebo test necessitates a long, uninterrupted pre-treatment window free from major shocks – something Ukraine's political and economic history cannot provide. Any pseudo-treatment date prior to 2013 would inevitably coincide with actual disruptions, thus confounding the inference. Consequently, the analysis emphasizes cross-unit placebo tests (also known as "in-space placebos") and leave-one-out robustness checks, both of which are standard and suitable in contexts with volatile pre-treatment dynamics (Abadie, Diamond, & Hainmueller, 2010).

6.2.1 Placebo Test

The placebo tests involve creating an identical synthetic control method in terms of predictors, donors, and period to other countries in the donor pool, treating them as if they had experienced a comparable intervention in 2013, and then comparing their post-2013 GDP gaps to Ukraine's. This approach helps determine whether a similarly large divergence might appear for countries that were not actually affected by conflict.

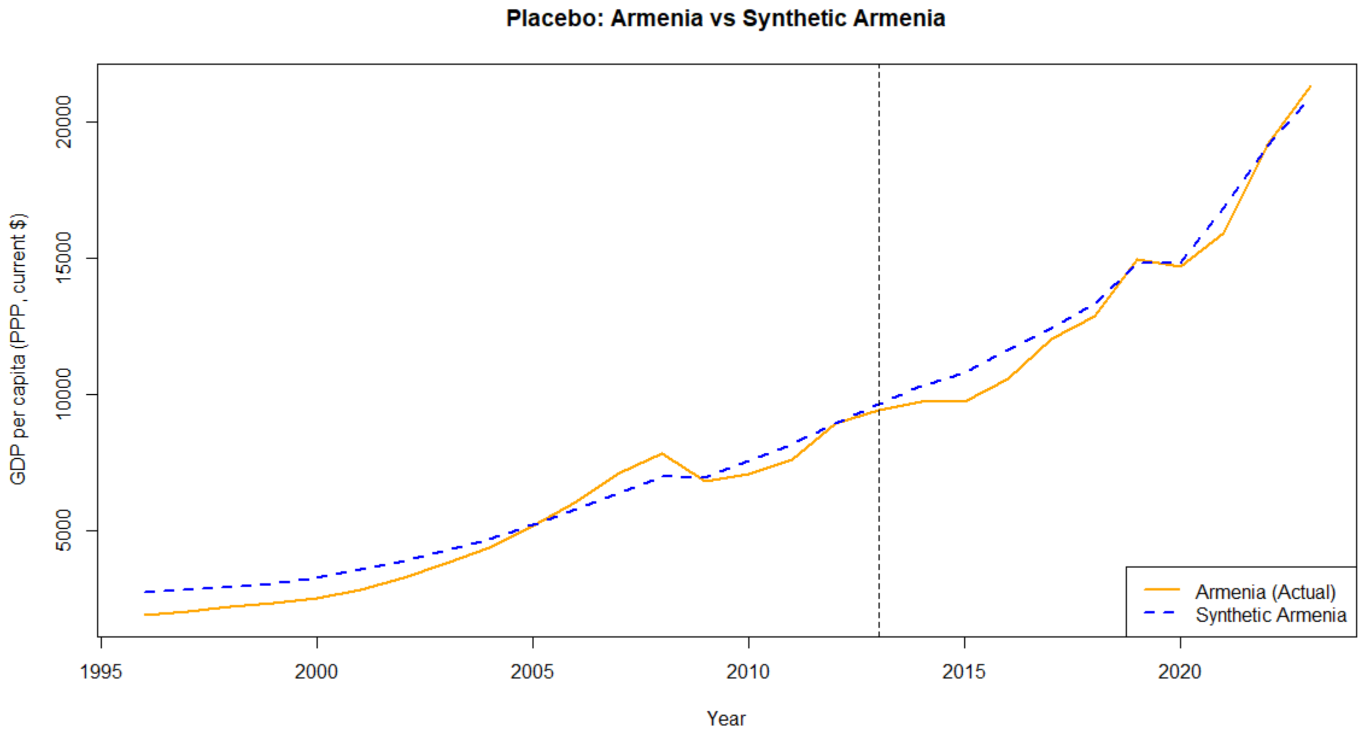


Figure 6.3. Placebo: Armenia vs. Synthetic Armenia (GDP per capita, PPP, 1996–2023)*. This graph serves as a placebo test to validate the SCM results for Ukraine by applying the same method to Armenia—a country unaffected by the 2014 Russia-Ukraine conflict. The dashed blue line shows the synthetic counterfactual for Armenia, while the orange line represents actual GDP per capita PPP. Following the 2014 placebo treatment year (vertical dashed line), no substantial divergence is observed between the two trajectories, indicating that the SCM model does not falsely attribute effects in countries not exposed to the conflict. This strengthens the causal interpretation of the GDP gap observed in the Ukrainian case. Source: Author's calculation using SCM in R.*

Notably, we conducted these placebo analyses for key donor countries, including Armenia, which were major contributors to the synthetic Ukraine. The comparative results reveal that Ukraine's post-2013 GDP per capita divergence is uniquely large. As shown in Figure 6.3, Armenia's actual GDP per capita remains closely aligned with its synthetic counterpart throughout the post-2013 period, showing only minor fluctuations that resemble random variation rather than a structural break. Quantitatively, Armenia's post-treatment RMSE is 600, while Hungary's is around 1000. Similarly, a placebo test for Romania, another transitional economy, yields a post-treatment RMSE of approximately 1200, an order of magnitude smaller than Ukraine's (both Hungary and Romania have twice the GDP per capita of Ukraine). In all these placebo cases, no persistent divergence is observed: the synthetic and actual trajectories remain aligned after 2013. This stark contrast reinforces the conclusion that Ukraine's observed gap is exceptional and not a common occurrence across unaffected countries. Formally, Ukraine's synthetic control estimate lies far outside the distribution of placebo effects generated for the donor pool, strongly supporting the interpretation that the 2014 conflict caused a genuine and sizable economic disruption, rather than the model capturing noise or structural drift unrelated to treatment.

6.2.2 Leave-One-Out Test

To further test the robustness of the results, a leave-one-out (jackknife) procedure was applied, systematically excluding each donor from the synthetic control model. In every case, the estimated treatment effect – the post-2013 GDP per capita gap – remained present and directionally consistent. The pre-treatment fit RMSE increased from the baseline value of 282 to a minimum of 338 (when Estonia was excluded), a median of 348.48, and a maximum of 600 when Moldova was excluded from the donor pool. Notably, excluding Hungary raised the RMSE to 348, Albania to 356, and Romania to 382. These increases confirm the relevance of the original donor composition, particularly the heavyweights like Armenia, Romania, and Hungary, but also demonstrate that no single donor drives the significant divergence. The synthetic Ukraine consistently overestimates actual GDP per capita after 2013, regardless of the donor configuration. Interestingly, although Moldova receives an extremely small weight in the baseline model (less than 0.0001), its exclusion can still cause a minor influence on robustness checks. This reflects Moldova's structural resemblance to Ukraine among post-Soviet economies. Despite its smaller size, it is arguably the closest economic analogue to Ukraine outside of Russia and Belarus. Overall, the persistence of the treatment effect across all specifications supports a robust, causal interpretation of Ukraine's observed GDP gap.

6.3 Recovery Scenario Outcomes

This section examines four recovery scenarios—Infrastructure-Led, Industrial Revitalization, Agricultural Recovery, and Balanced Recovery—by utilizing Ukraine's 2021 input–output data to evaluate the efficiency of translating final demand into gross output. It analyzes sectoral multipliers and demand-to-output ratios, revealing that strategies centered on intermediate-intensive sectors are more efficient, whereas others might offer wider but less effective recovery in terms of output.

6.3.1 Infrastructure-Led Recovery

To close the ₴325.6 billion GDP gap in this scenario, Ukraine would require ₴1,286 billion in additional gross output, supported by ₴775 billion in final demand, yielding a demand-to-output ratio of 0.603. This indicates that every ₴1 of new output requires about ₴0.6 of demand, with the rest generated through supply chains including imports.

The *construction sector* ($w_i = 0.35$) contributes the largest share of output (₴608.5 billion) with a ratio of 0.613, reflecting strong multiplier effects. Similarly efficient are *fabricated metal products* ($w_i = 0.05$, ₴82.9 billion output, 0.53 ratio) and professional services like *legal activities* ($w_i = 0.05$, ₴36.9 billion output, 0.51 ratio). On the other hand *electricity, gas, steam* ($w_i = 0.20$, ₴217.9 billion output, 0.697 ratio) and *transport and warehousing* ($w_i = 0.20$, ₴148.9 billion output, 0.71 ratio) require more direct demand to generate output. *Water supply* is the most demand-intensive, with a 0.859 ratio ($w_i = 0.05$, ₴58.8 billion output), while *telecommunications* follow at 0.81 (₴29.8 billion output). Despite its strategic role, the high demand-to-output ratio in the *water supply* and *telecommunications* sectors reflects its limited use of intermediate inputs and weak supply-chain linkages, meaning most spending directly funds services rather than stimulating broader economic activity. A standout is non-metallic mineral manufacturing, producing ₴102.6 billion in output from just ₴7.8 billion in demand—a very low 0.076 ratio, due to strong upstream linkages with construction.

Overall, the infrastructure-driven strategy shows that sectors with moderate intensities can transform small demand increases into substantial output through strong domestic connections. In this context, sectors with low demand-to-output ratios are especially valuable, as they amplify stimulus via the production network. While service components play a vital role in recovery, their elevated ratios suggest that output increases per UAH spent are more limited. This balance results in a measured situation, leveraging the economic framework to encourage recovery through capital investment and infrastructure restoration.

6.3.2 Industrial Revitalization

Under the Industrial Revitalization scenario, closing the ₴325.6 billion GDP gap requires approximately ₴1,863 billion in additional gross output, supported by ₴1,159 billion in final demand – the highest injection among all strategies. This results in a demand-to-output ratio of 0.622, meaning that every ₴1 of final demand generates roughly ₴1.61 in output. The efficiency stems from the intermediate-intensive nature of the industrial sectors prioritized, where supply chains are deep and input usage is high. Sectors such as the *manufacture of basic metals* ($w_i = 0.25$, ₴527.3B output, 0.543 ratio), *manufacture of chemicals* ($w_i = 0.1$, ₴290.2B, 0.544), and *manufacture of plastics* ($w_i = 0.1$, ₴241.5B, 0.579) show particularly strong multiplier effects, with relatively low demand requirements per unit of output, indicating robust linkages with upstream suppliers.

In contrast, some sectors display significantly higher demand-to-output ratios. For example, electrical equipment (₴116.0B output, 0.962 ratio) and other transport equipment (₴43.3B, 0.921) absorb nearly 1 UAH of final demand for each 1 UAH of output, suggesting limited supply-chain activation or higher reliance on imported components. These high-ratio sectors may also reflect technological complexity or capital intensity, where a larger share of demand goes into non-domestic or less interlinked uses. The lowest demand ratio is observed in coke production ($w_i = 0.05$, ₴152.6B, 0.452), demonstrating exceptional supply-chain activation and domestic integration.

The Industrial scenario stands out for its efficient transformation of demand into output, thanks to the broad and deep domestic industrial base. However, the variation in sectoral ratios also signals potential bottlenecks in some high-tech or capital-heavy sectors, which may require complementary policies—such as infrastructure investment or workforce training—to unlock their full productive potential.

6.3.3 Agricultural Recovery

In the Agricultural Recovery scenario, closing the ₴325.6 billion GDP gap requires roughly ₴1,198 billion in gross output, supported by a substantial ₴835 billion in final demand, the highest demand relative to output among all strategies. This results in an overall demand-to-output ratio of 0.697, reflecting a relatively inefficient conversion of spending into output. The inefficiency arises in part from the sectoral structure: agriculture and food production are characterized by higher value-added shares and limited domestic upstream linkages, reducing the multiplicative effect of demand injections. Final demand is especially concentrated in *food manufacturing* (w_i = 0.20), which alone requires ₴315 billion to generate ₴330 billion in output (ratio = 0.956), indicating minimal supply-chain amplification. Similarly, sectors like *water supply* (w_i = 0.05, ₴58.8B output, 0.852 ratio), *textiles* (w_i = 0.05, ₴33.5B, 0.810), and *pharmaceuticals* (w_i = 0.05, ₴52.7B, 0.656) require high levels of final demand per unit of output, suggesting weak intermediate linkages or significant import content.

While *agriculture* (w_i = 0.30) itself appears more efficient, producing ₴230 billion in output from just ₴85.1 billion in demand (ratio = 0.370), its overall influence is constrained by the structure of the supply chain. The more productive agro-processing sectors (like food and chemicals) still require large injections of final demand, limiting the strategy's total efficiency. Despite leveraging Ukraine's natural strengths, the Agricultural Recovery strategy requires more spending per unit of output, with diminishing returns.

6.3.4 Balanced Recovery

In the Balanced Recovery scenario, bridging the ₴325.6 billion GDP gap requires ₴1,090 billion in total output, funded by approximately ₴708 billion in final demand (ratio of 0.65). This scenario reflects the strategy's broad-based structure, which distributes investment across infrastructure, industry, agriculture, and services, blending the strengths and limitations of each. All weight distributions are on page 59.

Final demand is notably front-loaded in high-value-added sectors such as *education* (₴23.0B demand for ₴24.1B output; ratio = 0.955), *health* (₴32.5B for ₴34.0B; ratio = 0.956), and *food manufacturing* (₴82.8B for ₴86.8B; ratio = 0.953), where stimulus translates less efficiently into gross output. At the same time, more intermediate-intensive sectors like *construction* (₴101.5B demand for ₴183.0B output; ratio = 0.554), chemicals (₴97.9B for ₴152.7B; ratio = 0.642), and *basic metals* (₴57.2B for ₴111.0B; ratio = 0.515) amplify demand more effectively via strong supply-chain linkages. *Transport* stands out with the most efficient conversion (₴5.6B demand for ₴39.2B output; ratio = 0.142), significantly pulling down the average ratio and illustrating its strategic role as a demand-efficient sector. Meanwhile, *agriculture* (₴37.1B demand for ₴80.7B output; ratio = 0.459) continues to offer solid output returns with modest injections.

Altogether, the Balanced scenario achieves moderate stimulus efficiency while maintaining sectoral diversity. It mitigates the inefficiencies of service-heavy strategies and the high injection costs of agriculture, offering a resilient, flexible mix aligned with both short-term recovery and longer-term stability.

6.3.5 **Cross-Scenario Comparison**

Scenario	Output Required (₴B)	Final Demand (₴B)	Demand-to-Output Ratio
Infrastructure-Led	1,286	775	0.603
Industrial Revitalization	1,863	1,159	0.622
Agricultural Recovery	1,198	835	0.697
Balanced Recovery	1,090	708	0.650

Table 6.1. Cross-Scenario Comparison

The cross-scenario comparison highlights that while each recovery strategy meets the ₴325.6 billion GDP gap, they differ significantly in how efficiently final demand is translated into gross output, and crucially, in how the same sectors behave differently across contexts. The Industrial Revitalization scenario, though requiring the highest output (₴1,863B) and imposing the highest constraint on supply, leverages a strong demand multiplier (ratio = 0.622) due to its reliance on intermediate-intensive sectors like basic metals and chemicals.

In comparison, the Agricultural Recovery demands the most significant spending (₴835B) relative to output (₴1,198B), resulting in the highest ratio (0.697) and indicating weaker supply-chain effects in food and agriculture sectors. Notably, several sectors show up in multiple scenarios yet exhibit notably different demand-to-output ratios: for example, construction reliably provides effective stimulus returns, with demand ratios between 0.55 and 0.61 across various scenarios. This variation indicates that sectoral behavior is not static and is influenced by the wider production framework, demand composition, and the connections activated in each strategy. Ultimately, the Balanced scenario lands in a neutral position, presenting a combination of effective and ineffective sectors that stabilize overall performance. These insights highlight the need to customize policy not only for overall output objectives but also for sectoral dynamics, as the same industry can either enhance or diminish recovery effects based on its function within the stimulus framework.

Chapter 7: Economic Interpretation and Policy Implications

This chapter analyzes the results of the SCM–IO model and their policy implications, demonstrating how various recovery strategies can help address Ukraine's GDP gap. It highlights the model's strengths in static analysis while also acknowledging its shortcomings in considering dynamic factors such as labor constraints, fiscal pressures, and structural changes since 2022.

7.1 A Static Recovery Template

The combined SCM–IO framework offers a powerful tool for quantifying the economic damage caused by conflict and mapping viable recovery strategies. It shows that Ukraine's economy experienced a structural break post-2013, resulting in a GDP per capita (PPP) shortfall of $1,007 by 2021. When multiplied across the population and converted to a nominal value, this translates to an annual GDP loss of ₴325.6 billion, which serves as the benchmark for recovery planning throughout this thesis. Consequently, input–output simulations provide a comparative static view of how the GDP gap might be regenerated through various sectoral strategies. Notably, the analysis indicates that certain sectors, such as construction or metals, consistently demonstrate strong multiplier effects, while others, like water supply, require significant direct demand to produce output, highlighting their limited supply-chain effects. The same sector may perform differently across scenarios, depending on its surrounding industrial ecosystem. These patterns offer valuable insights on where public investment might be directed to bridge the gap, but this must be interpreted within real-world limitations.

7.2 Toward a Dynamic Planning Framework

While the SCM–IO framework developed in this thesis offers a precise and robust estimate of the stimulus needed to close Ukraine's GDP gap, it remains fundamentally a static tool. It models a one-time injection of final demand and traces its effects through the intersectoral structure of the economy based on fixed 2021 relationships. However, real-world recovery is a dynamic and evolving process. For this methodology to serve as a comprehensive instrument for economic planning, it must be extended to account for the temporal, institutional, and macroeconomic constraints that shape how the economy actually responds over time.

First among these omitted dynamics is labor supply. While the model assumes that the economy can produce additional output when there is demand, many sectors, particularly in industry and agriculture, face significant labor constraints due to migration, displacement, or conscription. A more advanced version of the framework would need to incorporate sector-specific labor availability and skill mismatches, as these could significantly limit the supply response to stimulus. Similarly, energy and infrastructure constraints are not currently modeled. For instance, while the construction sector displays strong multipliers in the IO model, its real-world performance heavily relies on access to materials, functioning roads, and reliable energy supply—all of which remain compromised in parts of Ukraine.

Fiscal sustainability is another critical factor overlooked in the current framework. Final demand injections are treated as externally financed and unconstrained, but in practice, Ukraine must balance these injections with limited public finances. A fiscal module would need to account for the sources of funding—taxes, debt, foreign grants, money supply—and the long-term fiscal implications of each. Related to this is the role of the external sector. Foreign aid, FDI, and export revenues are essential for Ukraine's recovery, yet the model assumes no balance-of-payments constraints. In reality, a surge in demand might widen the trade deficit unless matched by export growth or foreign capital inflows, which would necessitate modeling trade flows, aid disbursements, and investor behavior.

A deeper limitation is the lack of capital accumulation and technological upgrading. The IO model assumes fixed production coefficients and cannot capture how investment might enhance productivity over time. For example, a ₴100 billion investment in machinery may yield more than just the current output; it may increase the sector's future efficiency. These intertemporal effects can only be modeled by connecting the static IO core to a dynamic macroeconomic framework, such as a computable general equilibrium (CGE) model or a system dynamics approach. Such integration would enable endogenous response feedback loops, time lags, and capacity building, contributing to a more realistic recovery roadmap.

7.3 Structural Shifts and Data Uncertainty

The model presented in this thesis utilizes Ukraine's 2021 input–output matrix, which provides the latest comprehensive overview of sectoral interdependencies before the onset of the full-scale invasion. However, the war has significantly altered the economy, necessitating that any analysis based on prewar data takes these changes into account. Since 2022, the Ukrainian economy has undergone a remarkable shift: between 40% and 50% of the national budget is now directed toward defense expenditures, while private consumption has sharply declined due to mass displacement, falling incomes, and population loss in occupied areas (Samoiliuk, 2025). Consequently, the government has become the main driver of demand, reallocating resources towards defense production, critical infrastructure, and emergency services. This has resulted in a centralization of economic activity, with the defense sector becoming crucial in production, employment, and investment. These structural changes indicate that essential sectors—including defense manufacturing, logistics, and government services—have expanded significantly, while others, such as retail, leisure, and certain export-oriented industries, may have contracted or ceased operations.

While the 2021 IO table does not directly capture these dynamics, the SCM–IO framework developed here is well-suited to accommodate them. The model is intentionally comparative and scenario-based rather than predictive, allowing future iterations to incorporate updated sector weights, emerging industries, or shifts in final demand as new data becomes available. In that sense, its flexibility is a strength: it provides a solid architecture for testing recovery strategies under changing economic structures. In future work, this model can be expanded using updated IO tables or alternative real-time data sources, such as tax receipts, trade flows, or satellite indicators, to better approximate the post-invasion economy. Until then, the current results should be viewed not as fixed forecasts but as structured simulations—useful for stress testing Ukraine's recovery options and informing policy under deep uncertainty. Far from being rendered obsolete by structural shifts, the model supports their integration by offering a replicable methodology that can evolve alongside Ukraine's economy.

Chapter 8: Conclusion

This thesis examines the economic implications of the Russo-Ukrainian War and develops a quantitative framework to assess Ukraine's post-conflict recovery strategies. By combining the Synthetic Control Method (SCM) with Input–Output (IO) analysis, the research established a framework for an analytical tool that aligns macroeconomic damage estimates with actionable, sector-specific recovery pathways. The empirical findings illustrate the extent of wartime economic disruption in tangible terms. The SCM analysis estimates that by 2021, Ukraine's GDP per capita lagged behind its synthetic counterpart by approximately $1,007 (PPP), which, when adjusted for population size and converted at the PPP conversion factor, corresponds to a nominal GDP gap of ₴325.6 billion or about 6% of Gross Value Added. This figure aligns with contemporary research conducted throughout the conflict.

To validate the causal interpretation of Ukraine's GDP divergence observed post-2013 through SCM, the study performed various robustness and inference checks. In-time placebo tests, which simulate artificial treatments in earlier years, were deemed unsuitable due to Ukraine's unstable pre-2013 trajectory characterized by political and economic turmoil. Instead, the analysis employed cross-unit placebo tests and leave-one-out methods. The placebo tests utilized the SCM framework on key contributors from the donor pool—Armenia, Hungary, and Romania—none of which were directly impacted by the Russian aggression—and revealed no similar divergence between actual and synthetic GDP paths after 2013. Ukraine's post-treatment Root Mean Square Error (RMSE) exceeded 3,000 while the RMSEs for placebo countries remained below 3% of their highest GDP per capita, underscoring the distinctiveness and severity of Ukraine's economic shock. The leave-one-out tests bolstered the findings' robustness by showing that the estimated GDP gap endured across all donor exclusions, indicating that no individual donor was solely accountable for the result. Collectively, these findings strongly substantiate the conclusion that the 2014 conflict resulted in a genuine and significant economic disruption.

Moving on, using the GDP gap as a recovery target, the IO simulations translated this macro-level shortfall into specific sectoral demand needs across four distinct recovery scenarios: Infrastructure-Led, Industrial Revitalization, Agricultural Recovery, and a Balanced strategy. The results indicated considerable variation in how efficiently each strategy could mobilize economic output. For example, the Industrial Revitalization scenario required ₴1,159 billion in final demand to produce ₴1,863 billion in output, yielding a demand-to-output ratio of 0.622, which suggests strong multiplier effects through intermediate-intensive sectors such as basic metals, chemicals, and machinery. In contrast, the Agricultural Recovery scenario necessitated ₴835 billion in demand to generate ₴1,198 billion in output, with a higher ratio of 0.697, reflecting fewer upstream linkages within the industry, while remaining export-oriented. Infrastructure-led recovery demonstrated significant supply-chain activation in construction and materials (notably featuring a low demand/output ratio of 0.076 in non-metallic mineral production), whereas the Balanced strategy provided moderate efficiency by distributing investment across sectors.

This research offers both methodological and practical contributions to post-conflict economic recovery studies. Methodologically, it introduces an integration of the Synthetic Control Method with Input–Output modeling, forming a cohesive framework that connects macroeconomic causal inference with microeconomic policy formulation. The innovation involves converting an empirically estimated GDP gap, calculated via SCM, into specific, sector-based demand and output requirements through IO techniques. This combination transforms abstract economic losses into practical recovery benchmarks, facilitating a clearer understanding of how targeted sectoral investments can address the identified gap.

On the policy front, the integrated SCM–IO framework provides a transparent and flexible planning tool that can guide economic reconstruction in post-war contexts. It enables policymakers to assess not just how much additional output and demand is needed, but also to identify which sectors can efficiently generate it, considering the current supply constraints and Ukraine's economic structure. Scenarios derived from the model—each with distinct sectoral weightings, output targets, and demand-to-output ratios—facilitate the evaluation of trade-offs between efficiency, feasibility, and strategic priorities. By doing this, the framework transitions recovery planning from speculative narrative-making to structured, data-driven decision-making.

Nevertheless, this thesis also acknowledges several empirical limitations of the current analytical approach. The model, by design, is static and based on Ukraine's 2021 input–output; although it is the most recent version available as of May 2025, it no longer fully reflects the country's economic realities post-2022. To conduct any analysis or simulation of the contemporary situation, constraints such as war-induced labor shortages, displacement, capital destruction, energy disruptions, and the strategic reallocation of resources toward the defense sector must be considered. Additionally, the model does not explicitly account for macroeconomic balances such as fiscal and current account sustainability, foreign aid, or inflationary pressures. These omissions are not merely technical limitations but structural barriers that need to be addressed for the implementation of studies. Addressing them in future work—via dynamic IO models, constraint-aware simulations, real-time data integration, or —will be essential to enhance the model's applicability as an actual policy instrument. Additionally, more granular modeling at regional and sectoral levels, along with integration with real-time data sources, would further refine policy insights and provide timely decision-support tools for reconstruction. However, even in its current form, the framework lays the groundwork for a replicable, transparent, and policy-relevant approach to post-conflict economic planning.

In conclusion, this thesis emphasizes the critical importance of structured, data-driven recovery planning following destructive conflicts. By shifting the policy discourse from immediate crisis response to strategic, sustainable capacity-building, the proposed framework provides actionable insights for policymakers committed not only to restoring Ukraine's economy but also to transforming it into a more resilient and dynamic future. One cannot harvest sorrows, but with the right tools, one can harvest even a blast crater. This research serves not merely as an academic exercise but also as a practical call to action: structured, sector-aware, evidence-based recovery strategies are not only desirable but also essential for those who will rise from the ruins—the New Ukrainian state.

Appendix

Appendix A: Synthetic Control Method

Full Donor Pool with Weights: Poland (0.000002); Romania (0.3546); Bulgaria (0.00005); Latvia (0.00011); Lithuania (0.00001); Estonia (0.00005); Turkiye (0.00011); Croatia (0.00001); Bosnia and Herzegovina (0.00003); Moldova (0.0001); Georgia (0.00133); Armenia (0.5429); Albania (0.00014); Czechia (0.00016); Serbia (0.00001); Slovenia (0.00007); Hungary (0.1004); North Macedonia (0.00006)

Full List of Predictors: GNI per capita, PPP (current international $); Foreign direct investment, net inflows (% of GDP); Foreign direct investment, net inflows (BoP, current US$); Agriculture, forestry, and fishing, value added (% of GDP); Industry (including construction), value added (% of GDP); Services, value added (% of GDP); Current account balance (% of GDP); Net trade in goods and services (BoP, current US$); Domestic credit to private sector by banks (% of GDP); Exports of goods and services (% of GDP); Imports of goods and services (% of GDP); PPP conversion factor, GDP (LCU per international $); Monetary Sector credit to private sector (% GDP); GPD-GNI per capita PPP.

Predictor Variable Comparison: Ukraine vs. Synthetic Ukraine (Pre-Treatment Period)

Predictor	Ukraine	Synthetic Ukraine
Foreign direct investment, net inflows (BoP, current US$)	$4.06 billion	$3.01 billion
Net trade in goods and services (BoP, current US$)	-$3.49 billion	-$1.22 billion
GNI per capita, PPP (current international $)	$6,470	$6,510
GPD-GNI per capita PPP	218.0	233.0
PPP conversion factor, GDP (LCU per international $)	1.60	5.10
Imports of goods and services (% of GDP)	49.0%	64.4%
Services, value added (% of GDP)	48.8%	34.5%
Industry (including construction), value added (% of GDP)	28.9%	15.4%
Domestic credit to private sector by banks (% of GDP)	33.5%	21.8%
Monetary Sector credit to private sector (% GDP)	33.5%	21.9%
Exports of goods and services (% of GDP)	47.7%	38.3%
Current account balance (% of GDP)	-0.42%	-0.89%
Foreign direct investment, net inflows (% of GDP)	3.46%	5.33%
Agriculture, forestry, and fishing, value added (% of GDP)	9.89%	10.4%

Table: Ukraine vs. Synthetic GDP and Gap (1996–2023)

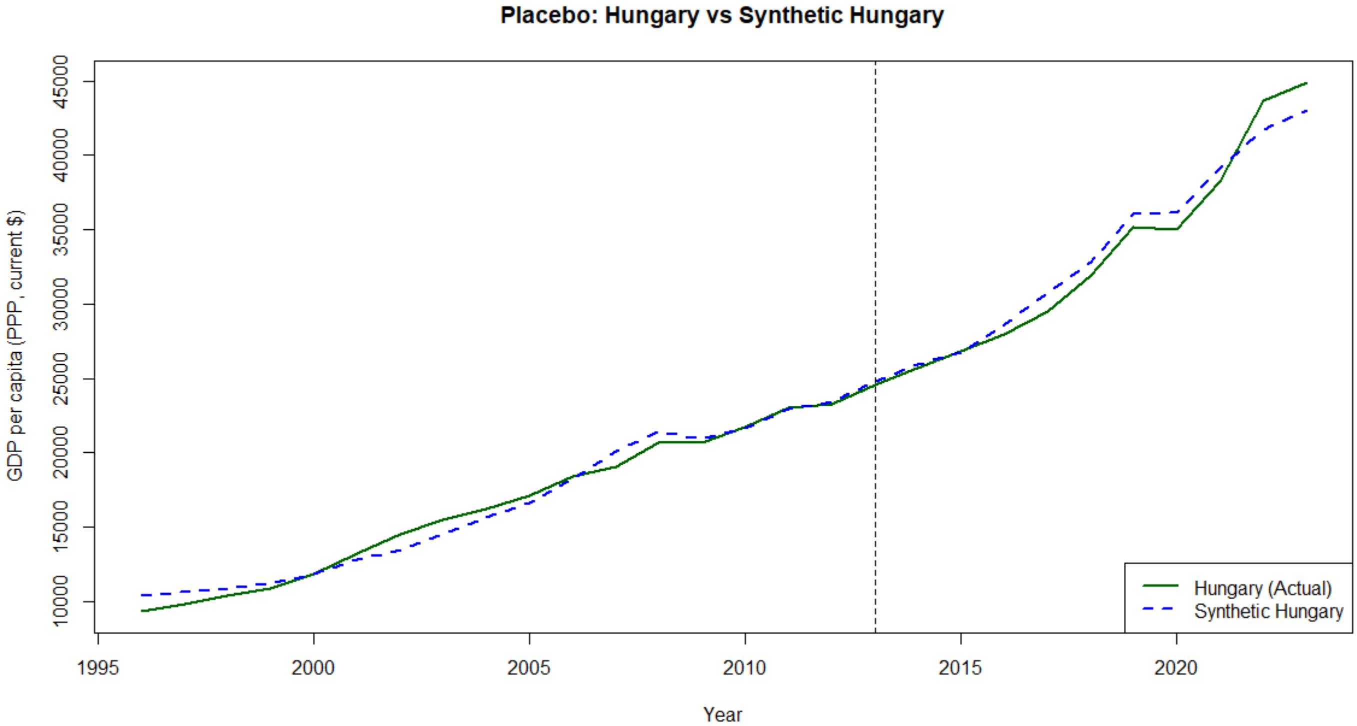
Year	Ukraine GDP	Synthetic GDP	Gap
1996	3,812.25	3,769.87	42.37
1997	3,794.18	3,972.88	-178.70
1998	3,794.34	4,026.11	-231.77
1999	3,871.33	4,147.01	-275.69
2000	4,228.12	4,364.69	-136.58
2001	4,746.86	4,710.04	36.82
2002	5,122.84	5,166.46	-43.61
2003	5,764.01	5,635.03	128.98
2004	6,663.47	6,223.97	439.50
2005	7,142.11	6,882.91	259.19
2006	7,971.20	7,616.26	354.94
2007	8,900.44	8,361.06	539.38
2008	9,323.72	9,115.22	208.51
2009	7,994.62	8,348.93	-354.31
2010	8,453.30	8,758.58	-305.28
2011	9,126.61	9,341.70	-215.09
2012	9,552.31	10,048.27	-495.96
2013	10,903.83	10,849.30	54.52
2014	10,493.75	11,268.88	-775.14
2015	9,921.83	11,656.71	-1,734.87
2016	10,864.66	12,785.42	-1,920.76
2017	11,536.08	14,085.29	-2,549.20
2018	12,554.85	14,957.82	-2,403.00
2019	14,217.49	16,924.95	-2,707.46
2020	15,541.03	16,831.61	-1,290.59
2021	**17,846.41**	**18,852.98**	**-1,006.57**
2022	14,770.07	20,909.08	-6,139.01
2023	17,630.13	22,622.50	-4,992.38

Model Fit Summary

Pre-treatment RMSE	282.52
Post-treatment RMSE	3,036.33
Post-/Pre-treatment RMSE Ratio	10.75

Note: A higher post-/pre-treatment RMSE ratio indicates a significant divergence between actual and synthetic outcomes following the intervention.

Place Test



Model Fit Summary for Hungary (GDP Range: 9,000 – 45,000)

Pre-treatment RMSE	601.89
Post-treatment RMSE	1147.50
Post-/Pre-treatment RMSE Ratio	1.9

Note: A higher post-/pre-treatment RMSE ratio indicates a significant divergence between actual and synthetic outcomes following the intervention.

Leava-One-Out Test

Pre-treatment RMSE with complete list of countries: 282.52

Leaving each country out of the model gives us:

Without a Country	Pre-treatment RMSE
Poland	389.86
Romania	382.35
Bulgaria	339.57
Latvia	390.41
Lithuania	342.05
Estonia	338.84
Turkiye	440.58
Croatia	347.10
Bosnia and Herzegovina	339.01
Moldova	600.78
Georgia	352.77
Armenia	347.94
Albania	356.34
Czechia	348.17
Serbia	339.73
Slovenia	391.06
Hungary	348.25
North Macedonia	348.71

Appendix B: Input–Output Model

List of sectors in the Input-Output Matrix and their share of Total Output (42 sectors in Total):

Agriculture (12.24%), Coal Mining (1.13%), Oil & Gas Extraction (1.51%), Other Mining (3.37%), Food & Beverages (7.82%), Textiles (0.41%), Wood & Paper (1.45%), Coke (0.85%), Petroleum Products (0.57%), Chemicals (1.20%), Pharmaceuticals (0.47%), Rubber & Plastics (0.73%), Non-metallic Minerals (1.69%), Basic Metals (5.44%), Fabricated Metals (0.89%), Electronics (0.16%), Electrical Equipment (0.46%), Machinery (0.75%), Motor Vehicles (0.33%), Other Transport Equipment (0.42%), Furniture & Repair (1.10%), Energy Supply (5.31%), Water & Waste (0.61%), Construction (7.03%), Trade (13.25%), Transport & Warehousing (5.75%), Postal Services (0.12%), Accommodation & Food (0.81%), Media & Publishing (0.46%), Telecommunications (0.72%), IT Services (3.04%), Finance & Insurance (2.13%), Real Estate (3.70%), Legal & Consulting (1.46%), Scientific R&D (0.38%), Advertising & Professional Services (0.95%), Admin Support (1.17%), Public Administration (3.79%), Education (2.90%), Health & Social Work (2.35%), Arts & Entertainment (0.44%), Other Services (0.63%).

Value Added Ratios by Sector:

Agriculture, forestry and fishing (0.42479); Mining of coal and lignite (0.43591); Extraction of crude petroleum and natural gas (0.72484); Other mining and quarrying (0.44228); Food products, beverages, tobacco (0.19738); Textiles, apparel, leather (0.48546); Wood, paper, printing (0.21615); Manufacture of coke (0.10667); Refined petroleum products (0.13569); Chemicals (0.11222); Pharmaceuticals (0.30886); Rubber and plastics (0.13485); Non-metallic minerals (0.15864); Basic metals (0.15439); Fabricated metal products (0.19629); Electronics (0.26532); Electrical equipment (0.28069); Machinery and equipment (0.30113); Motor vehicles (0.21924); Other transport equipment (0.37636); Furniture, repair, toys (0.36367); Electricity, gas, steam, air conditioning (0.29885); Water supply, waste management (0.27711); Construction (0.18731); Wholesale and retail trade (0.49072); Transport and warehousing (0.43734); Postal and courier services (0.62646); Accommodation and food (0.52875); Media, publishing, broadcasting (0.36867); Telecommunications (0.54608); IT services (0.55305); Finance and insurance (0.66524); Real estate (0.74654); Legal, accounting, consulting, engineering (0.44043); Scientific R&D (0.54710); Advertising and technical activities (0.55263); Admin and support services (0.50650); Public administration and defense (0.77743); Education (0.71083); Health and social care (0.50339); Arts and entertainment (0.63301); Other services (0.64738).

Sample (8 x 8 sectors) of the Input-Output table at basic prices, Ukraine, 2021

Таблиця "витрати-випуск" в основних цінах1 / Input–Output table at basic prices1	Код КВЕД / *NACE code*	Сільське, лісове та рибне господарство / *Agriculture, forestry and fishing*	Добування кам'яного та бурого вугілля / *Mining of coal and*	Добування сирої нафти та природного газу / *Extraction of*	Добування металевих руд, інших корисних копалин та розроблення кар'єрів; надання допоміжних послуг у сфері добувної	Виробництво харчових продуктів; напоїв та тютюнових	Текстильне виробництво, виробництво одягу, шкіри та інших	Виробництво деревини, паперу; поліграфічна діяльність та	Виробництво коксу та коксопродуктів / *Manufacture of coke*
		A01-A03	B05	B06	B07-B09	C10-C12	C13-C15	C16-C18	C19.1
Сільське, лісове та рибне господарство	A01-A03	300196	201		110	249470	227	11592	1
Добування кам'яного та бурого вугілля	B05	616	5419		6	150		13	60307
Добування сирої нафти та природного газу	B06	10286	9	4559	5379	15704	301	2738	284
Добування металевих руд, інших корисних копалин та розроблення кар'єрів; надання допоміжних послуг у сфері добувної промисловості та розроблення кар'єрів	B07-B09	877	1050	1451	22724	1923	56	84	48
Виробництво харчових продуктів; напоїв та тютюнових виробів	C10-C12	5421	6	1	15	35717	5	14	4
Текстильне виробництво, виробництво одягу, шкіри та інших матеріалів	C13-C15	181	140	32	287	115	8261	284	65
Виробництво деревини, паперу; поліграфічна діяльність та тиражування	C16-C18	2284	408	28	656	39934	284	46232	14
Виробництво коксу та коксопродуктів	C19.1	69	132		322	148		395	2731

Sample (8 x 8) of Liontief inverse, Ukraine, 2021

Діяльність у сферах права та бухгалтерського обліку; діяльність головних управлінь (хед-	Наукові дослідження та розробки / *Scientific research and development*	Рекламна діяльність і дослідження кон'юнктури ринку; наукова та технічна діяльність;	Діяльність у сфері адміністративного та допоміжного обслуговування /	Державне управління й оборона; обов'язкове соціальне страхування / *Public administration and*	Освіта / *Education*	Охорона здоров'я та надання соціальної допомоги / *Human health activities, residential care*	Мистецтво, спорт, розваги та відпочинок / *Arts, entertainment and recreation*	Надання інших видів послуг / *Other service activities*	
M69-M71	M72	M73-M75	N77-N82	O84	P85	Q86-Q88	R90-R93	S94-S96, T97	
0,0037	0,0046	0,0047	0,0114	0,0115	0,0134	0,0090	0,0067	0,0060	*Agriculture, forestry and fishing*
0,0180	0,0234	0,0122	0,0348	0,0151	0,0182	0,0266	0,0167	0,0182	*Mining of coal and lignite*
0,0361	0,0354	0,0211	0,0558	0,0253	0,0247	0,0437	0,0305	0,0355	*Extraction of crude petroleum and natural gas*
0,0263	0,0167	0,0115	0,0223	0,0105	0,0053	0,0150	0,0086	0,0115	*Mining of metal ores; other mining and quarrying; mining support service activities*
0,0005	0,0007	0,0012	0,0009	0,0013	0,0018	0,0025	0,0012	0,0007	*Manufacture of food products; beverages and tobacco products*
0,0012	0,0010	0,0025	0,0030	0,0026	0,0007	0,0019	0,0073	0,0046	*Manufacture of textiles, wearing apparel, leather and related products*
0,0097	0,0100	0,0171	0,0150	0,0273	0,0072	0,0159	0,0146	0,0242	*Manufacture of wood, paper, printing and reproduction*
0,0087	0,0091	0,0054	0,0094	0,0038	0,0024	0,0055	0,0034	0,0048	*Manufacture of coke*
0,0239	0,0172	0,0135	0,0363	0,0130	0,0105	0,0218	0,0153	0,0204	*Manufacture of refined petroleum products*

Table B.1: *Sectoral Allocation of Recovery Weights in the Infrastructure-Led Scenario*

Sector	Assigned Weight
Construction	0.35
Electricity, gas, steam and air conditioning supply	0.20
Transport, warehousing, household (including transport mark-up)	0.20
Water supply; sewerage, waste management and remediation activities	0.05
Telecommunications	0.05
Legal and accounting; management consultancy; architectural and engineering activities (technical services)	0.05
Manufacture of fabricated metal products, except machinery and equipment	0.05
Manufacture of other non-metallic mineral products	0.05

Table B.2: *Sectoral Weights Assigned in the Industrial Revitalization Scenario*

Sector	Assigned Weight
Manufacture of basic metals	0.25
Manufacture of machinery and equipment n.e.c.	0.15
Manufacture of fabricated metal products, except machinery and equipment	0.10
Manufacture of chemicals and chemical products	0.10
Manufacture of electrical equipment	0.10
Manufacture of rubber and plastic products	0.10
Manufacture of coke	0.05
Manufacture of refined petroleum products	0.05
Manufacture of other transport equipment	0.05
Manufacture of furniture; jewellery, musical instruments, toys; repair and installation of machinery	0.05

Table B.3*: Sectoral Weights Assigned in the Agricultural Recovery Scenario*

Sector	Assigned Weight
Agriculture, forestry and fishing	0.30
Manufacture of food products; beverages and tobacco products	0.20
Transport, warehousing household (including transport mark-up)	0.20
Manufacture of chemicals and chemical products	0.10
Manufacture of textiles, wearing apparel, leather and related products	0.05
Manufacture of machinery and equipment n.e.c.	0.05
Manufacture of basic pharmaceutical products and pharmaceutical preparations	0.05
Water supply; sewerage, waste management and remediation activities	0.05

Table B.4*: Sectoral Weights Assigned in the Balanced Recovery Scenario*

Sector	Assigned Weight
Agriculture, forestry and fishing	0.10
Manufacture of food products; beverages and tobacco products	0.05
Manufacture of textiles, wearing apparel, leather and related products	0.05
Manufacture of basic metals	0.05
Manufacture of chemicals and chemical products	0.05
Manufacture of machinery and equipment n.e.c.	0.05
Manufacture of motor vehicles, trailers and semi-trailers	0.05
Water supply; sewerage, waste management and remediation activities	0.05
Construction	0.10
Transport, warehousing household (including transport mark-up)	0.05
Computer programming, consultancy, and information service activities	0.05
Scientific research and development	0.05
Legal, accounting, architectural, and engineering activities	0.05
Human health activities and social work without accommodation	0.05
Education	0.05
Public administration and defence; compulsory social security	0.05
Real estate activities	0.05

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