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Tetiana Momot

t.momot@unf.edu

University of North Florida

Andres Gallo

University of North Florida

Inna Kraivska

O.M. Beketov National University of Urban Economy in Kharkiv

Angelo C. Azueta

University of North Florida

Bogdan Chalyy

University of North Florida

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Civil-Military Innovation Ecosystems and the Wartime Institutional Resilience Framework: Evidence from Ukraine

Tetiana Momot[1][0000-0001-7397-3565], Andres Gallo[1][0000-0003-4643-8107], Inna Kraivska[2][0000-0002-5701-8557], Angelo C. Azueta[1][0000-0001-9245-2378], Bogdan Chalyy[1][0009-0006-9082-9729]

[1]Economics & Geography Department, Coggin College of Business, University of North Florida, 1 UNF Drive, Jacksonville, 32224, Florida, USA

[2]Finance, Accounting and Business Security Department, O.M. Beketov National University of Urban Economy, 17 Chornohlazivska Street, Kharkiv, 61002, Ukraine

Corresponding author. E-mail: t.momot@unf.edu

Contributing authors: agallo@unf.edu; Inna.Kraivska@kname.edu.ua; n01501610@unf.edu; n01513050@unf.edu

This study develops the Wartime Institutional Resilience Framework (WIRF) to explain how regional governance systems preserve and reconfigure essential functionality under prolonged defensive-war pressure. WIR is conceptualized as a territorially differentiated, system-level outcome shaped by historically accumulated regional capacities, adaptive governance, and evolving Civil–Military Innovation Ecosystems (CMIEs). The framework is operationalized through a first-generation Wartime Institutional Resilience Index (WIR-I) for 24 Ukrainian oblasts over 2022-2025, covering fiscal continuity, administrative functionality, digital capacity, entrepreneurial adaptation, and formal labor-market resilience, while conflict severity is measured separately as external selection pressure. The findings reveal substantial regional heterogeneity. Fiscal continuity and digital capacity indicate the strongest and most robust positive associations with broader wartime functionality, while administrative functionality and entrepreneurial adaptation are more context-dependent, and formal labor-market resilience is not statistically supported. Conflict severity is negatively associated with WIR-I in pooled models. The study contributes an evolutionary perspective on wartime resilience by linking path dependence, regional innovation systems, adaptive governance, and civil–military relational networks within a common meso-level framework.

Key words: Wartime Institutional Resilience; Civil-Military Innovation Ecosystems; adaptive governance; Regional Innovation Systems; evolutionary economics; defensive war; regional resilience.

JEL Classification: B52; H56; O31; R11

1. Introduction

Ukraine's regional governance systems have operated since February 2022 under conditions of prolonged defensive war, facing military violence, infrastructure destruction, population displacement, fiscal strain, business disruption, labor-market dislocation, and persistent uncertainty. Despite these pressures, institutional performance has varied substantially across regions. Some oblasts have experienced severe disruption of public administration, economic activity, and infrastructure, while others have preserved moderate or comparatively strong levels of fiscal, administrative, digital, and socioeconomic functionality. This territorial variation raises a broader theoretical question: how do regional governance systems preserve essential functionality, adapt, and reorganize under prolonged wartime pressure?

Existing resilience research has generated important insights into societal, ecological, regional, and institutional adaptation, while evolutionary economics and regional innovation-system research emphasize path dependence, learning, resource recombination, and the emergence of new developmental trajectories under changing selection environments. Yet less attention has been devoted to wartime institutional resilience as an evolutionary process unfolding under prolonged defensive-war pressure and through increasingly interconnected civil–military, public, private, academic, civic, and transnational networks. In particular, there remains a need to explain why regions exposed to severe, persistent wartime disruption follow markedly different institutional trajectories.

This study addresses that problem through the Wartime Institutional Resilience Framework (WIRF). The framework conceptualizes defensive war as an evolving external selection pressure acting upon territorially differentiated regional governance systems. These systems enter the shock with historically accumulated institutional, economic, technological, human, infrastructural, and relational capacities shaped by previous regional development trajectories and Regional Innovation Systems (RISs). Under prolonged wartime pressure, some of these capacities are

mobilized and recombined through adaptive-governance processes operating across increasingly mission-oriented civil-military networks.

Within the WIRF, the Civil–Military Innovation Ecosystem (CMIE) is conceptualized as an evolving, path-dependent, meso-level relational infrastructure for adaptive governance. It connects heterogeneous public, military, private, academic, civic, and transnational actors through which information, technologies, operational feedback, financial resources, knowledge, and organizational capabilities can circulate. Adaptive governance is analytically distinct from the CMIE: it is the cross-cutting coordination process through which distributed capacities are sensed, mobilized, recombined, tested, selected, scaled, and, where effective, institutionally retained. Wartime Institutional Resilience (WIR) is therefore treated as an emergent system-level outcome of the oblast-centered regional governance system rather than as an attribute of any individual organization, capability, or network.

This evolutionary perspective differs from conceptions of resilience centered primarily on restoration of a pre-shock equilibrium. Under prolonged defensive-war conditions, institutional continuity may require substantial organizational and institutional change. Resistance, coping, adaptation, and transformation can coexist across governance functions, while successful wartime responses may alter subsequent institutional capacities through learning, new routines, strengthened networks, digital infrastructures, and new forms of civil–military coordination. WIR is therefore understood as the realized ability of a regional governance system to preserve and reconfigure essential functionality while continuously adapting to a changing selection environment.

To provide a first empirical operationalization of this framework, the study constructs a first-generation Wartime Institutional Resilience Index (WIR-I) for 24 Ukrainian oblasts between 2022–2025. The WIR-I captures five observable wartime governance functionality domains: fiscal continuity, administrative functionality, digital capacity, entrepreneurial adaptation, and formal labor-market resilience. These domains do not serve as direct measures of adaptive governance or the CMIE; instead, they serve as observable indicators of regional institutional functioning, through which larger adaptive processes can be empirically observed. Conflict severity is measured separately through a Conflict Severity Index (CSI) and treated as external defensive-war selection pressure.

The empirical strategy combines composite-index construction, spatial and component-level analysis, panel regression, source-frequency robustness tests, and supplementary evidence on regional innovation activity and cooperation. To avoid mechanical part–whole relationships, tests of individual WIR-I domains use reduced versions of the index that exclude the tested component. Supplementary innovation statistics contextualize the historically accumulated and relational capacities from which wartime CMIEs may evolve, rather than being incorporated as an additional WIR-I component.

The results provide differentiated support for WIRF. Conflict severity is strongly negatively associated with the full WIR-I in the pooled specification, but the relationship is not robust to oblast fixed effects, indicating that much of the observed association reflects persistent differences between regions rather than a uniform within-oblast response to changing conflict intensity. Fiscal continuity and digital capacity show the strongest positive and comparatively robust relationships with functionality across the remaining WIR-I domains. Administrative functionality and entrepreneurial adaptation are positively associated with broader wartime functionality in pooled specifications but are sensitive to alternative source-consistent specifications. Formal labor-market resilience, as measured by registered unemployment, is not statistically supported, highlighting the difficulty of observing labor-market adaptation through administrative registration data under displacement, migration, mobilization, and disrupted access.

These findings contribute to several literatures. First, the study extends evolutionary economic reasoning into the analysis of prolonged defensive-war conditions by treating conflict as a selection environment in which historically accumulated capabilities, routines, and institutional relationships are repeatedly tested and recombined. Second, it connects regional innovation-system research with wartime institutional adaptation by explaining how pre-existing regional capacities may evolve into more mission-oriented civil-military and transnational relational structures. Third, it advances resilience research by distinguishing the external pressure acting on a system from the adaptive processes and observable functionality through which resilience becomes manifest. Fourth, the WIR-I offers a first-generation empirical window into the multidimensional and territorially differentiated character of wartime institutional functionality while explicitly recognizing that the broader relational and processual mechanisms of the WIRF remain only partially observed.

Therefore, Ukraine serves not only as an important empirical case of contemporary wartime resilience but as a setting in which broader evolutionary questions concerning institutional adaptation, path dependence, relational coordination, and the retention of crisis-induced institutional dynamism can be investigated under exceptionally intense selection pressure. This study constructs an evolutionary framework and offers an initial empirical operationalization that future research - comparative, longitudinal, or network-based - can improve and validate.

Beyond its theoretical contribution, the study is intended to inform regional and national policymakers, local and regional public authorities, reconstruction and development agencies, international partners, and actors

participating in civil-military innovation and regional innovation networks. By distinguishing external wartime pressure from the functionality maintained under that pressure, the WIRF provides a comparative analytical tool to identify territorially differentiated resilience profiles, diagnose vulnerable governance domains, and recognize capacities that remain functional under severe disruption. This perspective may support more context-sensitive prioritization of fiscal, administrative, digital, entrepreneurial, and human-capital interventions rather than applying uniform resilience policies across regions exposed to fundamentally different wartime conditions.

The remainder of the research is organized as follows: Section 2 develops theoretical foundations linking evolutionary economics, Regional Innovation Systems, adaptive governance, CMIEs, and institutional resilience. Section 3 specifies the WIRF, its analytical components, hypotheses, and empirical operationalization. Section 4 presents the data, construction of the WIR-I and Conflict Severity Index, and regression strategy. Section 5 reports the spatial, component-level, regression, and supplementary innovation-system findings. Section 6 discusses implications and develops an agenda for subsequent generations of WIRF research. Section 7 delivers the conclusion.

2. Literature Review and Theoretical Foundations

2.1 Evolutionary Economics, Institutional Adaptation, and Defensive-War Selection Pressure

The theoretical foundation of the Wartime Institutional Resilience Framework (WIRF) integrates insights from evolutionary economics, institutional theory, innovation ecosystem research, resilience theory, and defensive-war sociology to explain how governance systems adapt and transform under conditions of prolonged defensive war.

Schumpeter's concept of creative response, which distinguishes transformative innovation from routine adaptive adjustment, provides the starting point for this analysis. Schumpeter contends that creative responses generate fundamentally new, non-routine, and unpredictable reactions to crises that cannot be directly derived from existing conditions but can only be understood retrospectively through institutional and historical analysis (Schumpeter 1947). Unlike adaptive adjustments that aim to restore equilibrium, creative responses alter developmental trajectories by establishing new institutional, technological, and organizational pathways, making a return to the previous state impossible. Entrepreneurial agency, therefore, functions as a mechanism through which institutions recombine existing resources, routines, and knowledge in innovative ways. Consequently, creative response serves as a mechanism of evolutionary economic change, emphasizing novelty, experimentation, selection, and path dependence over static efficiency or equilibrium stability. In the context of defensive war, creative responses extend beyond entrepreneurial innovation to encompass institutional recombination, adaptive governance, and new forms of civil-military coordination. This interpretation establishes the conceptual foundation of WIRF: resilience emerges through the creation of new institutional pathways rather than through the restoration of pre-war equilibrium.

Subsequent developments in evolutionary economics expanded Schumpeter's insights by conceptualizing innovation as a dynamic process shaped by routines, institutional co-evolution, and learning under uncertainty. Nelson and Winter demonstrate how organizational routines and competitive selection mechanisms produce persistent patterns of technological and institutional change, while innovation systems research highlights the roles of governments, firms, universities, and civic networks in producing and diffusing innovation (Nelson and Winter 1982). Both technological change and institutional adaptation co-evolve through reciprocal feedback processes in which governance structures shape innovation trajectories while innovation simultaneously restructures institutional coordination mechanisms. Nelson's later work further expands the evolutionary perspective by emphasizing the co-evolution of technology, institutions, and economic performance, driven by interactions among firms, governance systems, research organizations, and policy structures (Nelson 1996; Nelson 2005). Similarly, Nelson argues that long-term economic growth depends not only on technological innovation itself but also on the institutional arrangements that shape learning, coordination, and adaptation (Nelson 2005). From this perspective, institutions function not merely as constraints but as evolutionary coordination mechanisms that shape the generation, diffusion, and retention of innovation under uncertainty. This provides the second conceptual foundation of WIRF, emphasizing that institutional resilience depends on the co-evolution of governance structures and innovation processes.

Hodgson's evolutionary institutional theory provides an important theoretical foundation for understanding institutions as adaptive rule systems shaped by routines, habits, and historically embedded learning processes that influence organizational behavior over time (Hodgson 1997). Hodgson conceptualizes institutions as systems of established social rules that structure interaction (Hodgson 2006). Institutions evolve by modifying, reinforcing, and selectively retaining these rule systems as conditions change. From this perspective, institutional adaptation reflects governance systems' capacity to revise, recombine, and selectively retain organizational rules, routines, and coordination mechanisms in response to changing environmental conditions. Consequently, institutional resilience

depends not on static efficiency but on the ability to generate adaptive variation, process information, and coordinate heterogeneous actors through rule-guided behavior (Hodgson 1988; Hodgson 2004). This evolutionary institutional perspective provides another theoretical pillar of the WIRF by explaining the processes of institutional adaptation through which wartime institutional resilience may emerge.

Dopfer and Potts extend the evolutionary perspective through a micro-meso-macro framework in which novel combinations generated at the micro level advance into meso-level institutional routines and ultimately reshape macro-level structural transformations (Dopfer and Potts 2008). Evolutionary institutional adaptation, therefore, emerges not as a linear adjustment process but as a cumulative dynamic of experimentation, coordination, selection, and retention operating across interconnected institutional levels. This framework provides the theoretical basis for conceptualizing CMIEs as meso-level relational infrastructures for adaptive governance that connect localized experimentation and adaptive learning with broader institutional transformation under wartime conditions.

Building on this evolutionary logic, Metcalfe conceptualizes economic and institutional change as a process of creative destruction operating within evolving selection environments (Metcalfe 1997; Metcalfe 1998). Metcalfe argues that crises intensify the mechanisms of variation, selection, and retention by disrupting established routines and exposing institutions to heightened competitive and adaptive pressures (Metcalfe 1994; Metcalfe 1998). In his view, creative destruction is not limited to technological innovation; it also encompasses the reorganization of institutional structures, governance routines, and coordination mechanisms in response to environmental shocks. Under wartime conditions, the destruction of existing infrastructure, administrative routines, and organizational capabilities creates a radically altered selection environment in which governance systems must rapidly learn, experiment, reallocate existing resources, and stabilize effective organizational creative responses.

However, the institutional consequences of war selection pressure depend critically on the nature of the conflict, as different forms of warfare produce distinct patterns of institutional adaptation, resource mobilization, and societal coordination. Political sociology and strategic studies distinguish between offensive wars oriented toward conquest or territorial expansion and defensive wars in which societies mobilize to preserve sovereignty, political order, territorial integrity, and collective identity (Clausewitz 1976; Walzer 1977; Malešević 2010). This distinction is particularly important for understanding institutional adaptation. Offensive or expeditionary wars typically rely more heavily on centralized military command structures, hierarchical coordination, and professional standing armed forces. By contrast, defensive wars, particularly existential wars for sovereignty and territorial integrity, increasingly require not only the activation of regular armed forces but also broader societal mobilization (including reservists, territorial defense formations, local authorities, businesses, universities, technological communities, civil society organizations, volunteer networks, and international partners), decentralized coordination, horizontal solidarity networks, and intensified civic participation (Tilly 1990; Malešević 2010). As a result, this expansion of whole-of-society participation alters the institutional architecture of wartime adaptation by bringing civilian and military actors into increasingly dense networks of coordination, resource mobilization, knowledge exchange, and problem-solving, in which vertical authority coexists with decentralized initiatives, horizontal networks, and intensified civic participation.

Under defensive-war conditions, physical infrastructure and established organizational routines are disrupted, decision-making time is compressed, demand structures shift, and urgent technological, administrative, humanitarian, and security needs emerge. These simultaneous disruptions fundamentally alter the selection environment in which regional governance systems operate, reducing the viability of established routines while increasing the value of rapid experimentation, learning, and resource recombination.

From an evolutionary perspective, a defensive war shock can also be viewed as an evolutionary accelerator that compels institutions to abandon ineffective routines, generate adaptive variation, learn under changing conditions, and selectively retain governance practices that sustain institutional functionality under prolonged uncertainty. This interpretation provides a key theoretical foundation for WIRF, in which conflict severity is conceptualized as an external selection pressure that continuously tests the adaptive capacity of regional governance systems.

Taken together, these evolutionary perspectives frame institutional adaptation as a cumulative process of variation, experimentation, learning, selection, and retention rather than as a return to a pre-shock equilibrium. Defensive-war shock acts simultaneously as a source of disruption and an evolutionary accelerator, intensifying selection pressures on existing institutional and organizational arrangements and shortening the cycles through which alternative responses are generated, tested, selected, and retained. However, the capacity of regional governance systems to generate and sustain creative responses under defensive-war selection pressure depends on historically accumulated organizational capabilities, institutional arrangements, knowledge infrastructures, actor networks, and relational resources. This shifts the analysis from the evolutionary logic of institutional change to the territorially embedded systems through which such adaptive capabilities are accumulated, connected, and mobilized, thereby providing the conceptual bridge to Regional Innovation Systems (RISs).

2.2 Regional Innovation Systems (RISs), Adaptive Governance, and the Evolution of Civil-Military Innovation Ecosystems (CMIEs)

Regional Innovation Systems (RIS) provide the territorial and organizational setting through which innovation, learning, and institutional adaptation become embedded at the meso-level. While evolutionary economics explains why institutions change under shifting selection environments, the RIS perspective clarifies how territorially embedded heterogeneous organizations interact within institutional environments, knowledge infrastructures, and relational networks to collectively generate and institutionalize innovation and adaptive responses (Cantner 2016). This territorial perspective is vital for understanding how institutions adapt during defensive-war pressure, as the ability to produce and sustain innovative responses also relies on the skills and connections developed within regional systems.

Innovation-systems research extends this evolutionary logic by framing innovation as a cumulative, interactive, and co-evolutionary process rather than an isolated technological outcome. Adaptive capacity depends on heterogeneous organizations' ability to generate alternative responses, exchange and recombine knowledge and resources, learn from feedback, and selectively retain effective practices under changing conditions. Therefore, innovation systems provide organizational, institutional, and relational conditions that embed evolutionary processes of variation, learning, selection, and retention in collective problem-solving. At the regional level, such processes are territorially differentiated as organizations, institutions, knowledge infrastructures, and networks develop along historically specific trajectories.

Cooke, Uranga, and Etxebarria conceptualize RIS as evolutionary configurations of organizations and institutions embedded in a territorially specific environment, aimed at increasing the system's innovative capacity (Cooke et al. 1998). The collective's framework distinguishes organizations, such as firms, universities, public agencies, financial institutions, and research bodies, from institutions, understood as norms, rules, conventions, and routines that serve as the 'glue' linking the organizational 'pieces', notably in systems of innovation (Lipparini and Sobrero 1994). Innovation capacity depends not only on the presence of organizations but also on the strength of the institutional and relational frameworks that enable these organizations to interact, share knowledge, and coordinate activities.

Tura and Harmaakorpi further develop the relational dimension of RIS by applying the resource-based view of social capital to define it functionally as a field-specific social resource of an actor (Tura and Harmaakorpi 2005). They defined regional innovation as a socially embedded, non-linear process generated through heterogeneous networks of firms, universities, technology organizations, public actors, and other regional organizations. From this perspective, social capital contributes to regional innovative capability by facilitating information exchange, cooperation, collective learning, and access to distributed material, economic, intellectual, and relational resources. Importantly, **s**ocial capital tends to be high in communities with a high average level of personal trust and in which public institutions are non-corrupt and trustworthy. Social capital is therefore relevant not merely because trust relationships exist, but because these relationships enhance actors' capacity to access and mobilize resources. Moreover, dividing social capital into bridging and bonding becomes crucial for assessing regional innovativeness. The balance between bonding and bridging social capital is particularly applicable: bonding ties support trust and cohesion within innovation networks, whereas bridging ties connect heterogeneous groups and facilitate access to new information, knowledge, and resources across organizational and sectoral boundaries (Granovetter 1985; Putnam 2000).

Regional innovative capability can therefore be understood as an emergent property of the regional innovation network: the collective capacity of heterogeneous organizations to access, mobilize, recombine, and renew distributed resources under changing conditions. This capability is fundamentally systemic, interactive, socially embedded, and path-dependent. It relies not only on the resources each organization has but also on the quality, diversity, and cross-field connectivity of their relationships. Tura and Harmaakorpi similarly emphasize that regional innovative capability depends less on the sheer number of relationships than on their diversity and on actors' ability to exploit resources available through cross-field connections (Tura and Harmaakorpi 2005).

On this basis, a Regional Innovation System is conceptualized here as a territorially embedded and historically evolving configuration of heterogeneous organizations operating within a regional institutional environment and connected through formal and informal actor networks. Organizations provide distributed knowledge, resources, and competencies; institutions structure their interactions through rules, norms, conventions, and routines; actor-networks constitute the relational architecture through which knowledge and resources circulate; and social capital enables actors to access and mobilize resources through these relationships. Regional innovative capability emerges from the interaction of these organizational, institutional, and relational elements rather than from

the isolated capabilities of individual actors. This interpretation is consistent with Cooke, Uranga, and Etxebarria's evolutionary conception of RIS, which emphasizes the distinction between organizations and institutions, the importance of formal and informal networks, learning, and hard and soft infrastructures in shaping regional systemic innovation capacity (Cooke et al. 1998). The effectiveness of these networks depends on the balance between bonding ties that sustain trust and cohesion and bridging or cross-field connections that provide access to diverse knowledge, external resources, and new partners.

In this respect, the strength of RIS depends on both material and relational capacities. Cooke et al. distinguish hard and soft infrastructures (Cooke et al. 1998). Material (hard) foundations include financial mechanisms, communication and technological infrastructures, universities, research and training organizations, technology-transfer structures, and policy capabilities, while relational (soft) foundations include embeddedness, networking competence, reciprocity, trust-based interaction, and interactive learning. Importantly, regional innovative capability cannot be reduced to conventional measures such as research and development (R&D) expenditure or patenting since learning capacity, networking competence, embedded knowledge, and other forms of relational interaction may be equally important for systemic innovation.

However, these innovation capacities do not develop independently of the broader regional governance system. Regional governance provides the institutional, policy, fiscal, and infrastructural environment within which RIS actors operate, while also facilitating interaction among relatively autonomous organizations, reducing uncertainty and transaction costs, and supporting the coordination of distributed regional capabilities. Cooke et al., for example, identify facilitating interaction, competence, reputation, trust, and reliability as important tasks of regional governance and emphasize the role of regional budgetary competence in mobilizing innovative capability (Cooke et al. 1998). Concurrently, the relationship is reciprocal: the RIS contributes to regional governance by generating knowledge, technological solutions, organizational practices, collaborative arrangements, and learning processes that can reshape governance priorities and institutional routines. The relationship between regional governance and RIS is therefore co-evolutionary rather than hierarchical.

Within this co-evolutionary relationship, interactive learning, feedback, experimentation, and resource recombination allow regional actors to respond to changing environmental conditions. Innovation-system and ecosystem research shows that actors simultaneously navigate cooperation and competition while developing innovation through relational learning, flexible collaboration, and continuous experimentation (Lundvall 2016; Hannah and Eisenhardt 2018). Through interactive learning, user-producer feedback, and iterative adaptation, RISs facilitate collective problem-solving and organizational learning under conditions of uncertainty. These processes generate alternative responses, enable actors to revise existing practices, and support the recombination of knowledge and resources as environmental conditions change. However, their effectiveness depends on the historically accumulated configuration of organizations, institutions, networks, and regional capabilities within which these interactions take place. Regional evolutionary economics reinforces this argument by emphasizing that such capacities are historically accumulated and territorially differentiated. Boschma highlights that adaptation to external shocks depends on pre-existing institutional diversity, related variety, and regions' capacity to generate new developmental pathways through recombination and adaptive branching (Boschma 2015). From this perspective, adaptation is path-dependent: regional adaptive capacity depends on historically accumulated institutional, technological, civic, and organizational capabilities that shape the range of feasible responses during a crisis. These inherited differences shape both the range of responses available to regional actors and their capacity to generate new developmental pathways under external pressure. Accordingly, RIS exposed to comparable shocks may follow substantially different adaptive trajectories. Regions with diversified knowledge bases, dense institutional networks, strong administrative capacity, and flexible coordination structures are better positioned to reorganize and generate new pathways under shock conditions.

The path-dependent and territorially differentiated character of RIS becomes particularly consequential under defensive-war pressure. Such a shock does not create adaptive capabilities de novo; rather, it subjects historically accumulated regional capabilities and relationships to intensified selection pressure, testing whether they can be rapidly activated, redirected, and recombined to sustain essential regional governance functions under radically altered conditions. At the same time, wartime pressures are spatially uneven, as regions differ substantially in their exposure to military violence, infrastructure destruction, displacement, economic disruption, and administrative strain. Wartime institutional adaptation varies across regions rather than following a single national pattern. It must be examined through regional differences in institutional and innovative capacities, influenced by factors such as pre-war governance quality, regional innovation systems, civic mobilization, entrepreneurial structures, digital infrastructure, and other inherited resources. These regional differences are crucial to the WIRF, as variations in regional institutional resilience during wartime are driven not only by external pressures but also by how effectively regional governance can mobilize, reconfigure, and utilize its existing resources and networks in response.

However, historically accumulated innovative and relational capabilities are not sufficient on their own for an effective response to a defensive-war shock. Their adaptive value depends on whether the regional governance system can rapidly activate, coordinate, and reconfigure distributed capabilities as threats, priorities, and resource constraints change. Under conditions of compressed decision-making time, recurrent disruption, extreme uncertainty, and rapidly changing technological and operational requirements, conventional governance routines may become insufficient. Thus, regional governance must operate in a more adaptive mode, combining institutional flexibility with decentralized problem-solving, cross-sector coordination, continuous feedback, and rapid resource reallocation.

Within the WIRF, adaptive governance is defined as the dynamic coordination process through which the regional governance system mobilizes and reconfigures distributed organizational, technological, institutional, and relational capabilities in response to changing defensive-war conditions. Adaptive governance represents a mode of coordination characterized by continuous sensing and feedback, flexible decision-making, cross-sector interaction, experimentation, resource recombination, and the selective retention of effective responses (Olsson et al. 2006; Gustafsson et al. 2025). Its central role is to translate the latent adaptive potential accumulated within the RIS into coordinated responses that sustain essential regional governance functionality under intensified selection pressure.

Through repeated cycles of network activation, experimentation, operational feedback, resource recombination, and organizational learning, the RIS progressively acquires a more mission-oriented, civil-military, and transnational configuration. This evolutionary reconfiguration provides the basis for the emergence of a Civil-Military Innovation Ecosystem (CMIE). Mission-oriented innovation scholarship complements this evolutionary perspective by emphasizing the state's strategic role in reducing uncertainty, mobilizing resources, coordinating distributed capabilities, and aligning heterogeneous actors toward shared societal objectives (Mazzucato 2018). Under defensive-war conditions, mission orientation becomes especially relevant, as urgent security and societal needs require rapid alignment of public, military, private, academic, and civic capabilities around concrete problem-solving missions. In Ukraine, this process is reflected in rapid regulatory adaptation, decentralized crisis management, expanded digital governance, emergency procurement, humanitarian coordination, and the growing integration of civil–military innovation networks into governance processes.

Accordingly, this study conceptualizes civil-military innovation ecosystems (CMIEs) as an evolving, mission-oriented, path-dependent meso-level relational infrastructure for adaptive governance that connects heterogeneous civilian and military actors across public, private, academic, civic, and transnational domains to identify emerging problems, exchange knowledge, experiment with alternative solutions, integrate operational feedback, mobilize and recombine distributed resources, and select, scale, and diffuse effective innovations under defensive-war conditions. The CMIE does not replace the pre-war RIS; rather, it represents its wartime evolutionary reconfiguration and extension across organizational, sectoral, civilian-military, and increasingly transnational boundaries.

As wartime innovation networks become increasingly connected to foreign governments, defense partners, international organizations, diaspora networks, multinational firms, research institutions, investors, and external technology communities, the CMIE extends beyond the regional and national scale. Under conditions of prolonged defensive war, foreign support assumes an exceptional role by providing access not only to financial and material resources, but also to advanced technologies, specialized knowledge, operational experience, international standards, and external innovation networks that may not be available domestically. Transnational embeddedness therefore expands the pool of knowledge, finance, technologies, and organizational capabilities available to regional actors while creating additional channels for learning, interoperability, diffusion, and scaling. In this sense, foreign support functions not merely as an external input but as an important enabling condition for the wartime CMIE's expansion and adaptive capacity. The wartime CMIE is best understood as a transnational extension and evolutionary reconfiguration of pre-existing regional and national innovation capacities.

Ukraine uniquely illustrates wartime reconfiguration. Ukraine's wartime innovation architecture combines pre-existing defense-industrial capabilities with increasingly decentralized, cross-sector networks linking state institutions, the Armed Forces of Ukraine (UAF), IT firms, small and medium-sized enterprises (SMEs), startups, universities, volunteer organizations, civic initiatives, and transnational partners. Battlefield and user feedback, rapid experimentation, adaptive procurement, digital coordination, and cross-sector collaboration have intensified the density and diversity of relationships among these actors, accelerating the reconfiguration of pre-war innovation capacities into a transnational CMIE. This process aligns with Cantner's emphasis on heterogeneity, institutional diversity, and dynamic selection mechanisms, as well as with Dopfer and Potts' micro-meso-macro conception of evolutionary change (Cantner 2016; Dopfer and Potts 2008). In alignment with Metcalfe's conceptualization of crises as intensified selection environments, wherein established routines are destabilized, and organizations are subjected to heightened pressures for experimentation, learning, and adaptation, CMIEs may be understood not simply as systems of technological innovation, but as mission-oriented relational infrastructures that enable collective learning, interorganizational coordination, resource recombination, and institutional adaptation (Metcalfe 1998). From this

perspective, CMIEs constitute an important governance architecture through which adaptive capacity can be mobilized and sustained under conditions of defensive war.

The emergence of a CMIE, however, should not be equated with adaptive governance itself. The CMIE provides the relational architecture through which defensive-war adaptive governance operates, whereas adaptive governance constitutes the dynamic operating logic through which this architecture is activated, coordinated, and continuously reconfigured. Within the CMIE, adaptive governance enables heterogeneous and relatively autonomous actors to integrate rapidly changing information, coordinate complementary capabilities, mobilize and recombine distributed resources, experiment with alternative responses, and selectively stabilize effective organizational and institutional solutions.

From an evolutionary perspective, adaptive governance serves as a meso-level coordination mechanism that enables the selection, retention, and institutionalization of localized experimentation, potentially contributing to broader structural transformation. The perspective facilitates the generation of adaptive variation, the integration of feedback, the reorganization of administrative routines, the selection and scaling of effective responses, and the retention of successful organizational and institutional practices under intensified wartime selection pressure. In this process, innovation accelerates adaptation by shortening cycles, broadening the range of feasible responses, and enabling the rapid recombination of distributed knowledge, technologies, and resources.

This interpretation is consistent with resilience scholarship that conceptualizes wartime resilience as a dynamic, multi-actor process shaped by interactions among formal institutions, non-state actors, hybrid governance networks, and digital systems. Under prolonged defensive-war conditions, adaptive governance, innovation, and collective agency become mutually reinforcing mechanisms through which governance systems preserve essential functionality while simultaneously reorganizing and developing new institutional capabilities (Melnykovska and Wilson Sokhey 2025; Kutsenko 2025). On this basis, defensive-war adaptive governance within the CMIE can be specified through interrelated process functions that convert distributed ecosystem capabilities into coordinated adaptive responses.

The CMIE provides the analytical bridge between RIS theory and Wartime Institutional Resilience. RIS theory explains how territorially embedded capabilities accumulate over time; defensive-war selection pressure explains how these capacities are tested and reoriented; and adaptive governance explains how they are mobilized and recombined under wartime conditions. The CMIE represents the meso-level relational infrastructure through which civilian, military, public, private, academic, civic, and transnational actors generate, select, and diffuse adaptive responses. Resilience theory then explains how these processes support the continuity, adaptation, and transformation of essential regional governance functions. Within WIRF, WIR emerges from the interaction of heterogeneous actors within the CMIE as adaptive governance mobilizes, coordinates, and recombines distributed capabilities to sustain and transform essential regional governance functions under defensive-war pressure.

2.3 Wartime Institutional Resilience (WIR) as an Emergent Outcome of Adaptive Governance across the Civil-Military Innovation Ecosystem (CMIE)

The concept of resilience has evolved from its origins in engineering and ecological science toward a broader understanding of how complex systems persist, adapt, and transform under disruption. Early approaches conceptualized resilience primarily as the capacity of systems to “bounce back” after disruption, emphasizing stability, restoring equilibrium, and recovery. More recent scholarship increasingly understands resilience as a dynamic and adaptive process through which systems maintain, reorganize, or transform their essential functions under persistent stress (Davoudi 2012; Bourbeau 2013). The distinction is particularly important under prolonged defensive-war conditions, where a return to the pre-war state may be neither possible nor desirable, and continued functionality increasingly depends on institutional adaptation.

Ecological and socio-ecological resilience theory provides an important foundation for this conceptual shift. Holling distinguishes engineering stability and ecological resilience, arguing that resilient systems can absorb shocks or changes in state variables, driving variables, and parameters, and persist and reorganize without collapsing into fundamentally different regimes (Holling 1973). Pimm further demonstrates that resilience depends not simply on the number of system components but on the structure and strength of their interactions (Pimm 1984). Pimm distinguished between resilience (speed of return to equilibrium) and persistence (ability to avoid collapse), showing that systems with tightly coupled interactions may be efficient but fragile under extreme disruption, underscoring the importance of diversity, flexibility, redundancy, and adaptive capacity. From a human-environment perspective, resilience increasingly came to be understood as a system's capacity to absorb disturbance, reorganize, learn, and continue functioning under changing conditions (Klein et al. 2003; Adger et al. 2005; Folke 2006). These insights are highly

relevant to wartime contexts, where rigid and overly centralized governance systems often face severe limitations under rapidly changing security, humanitarian, fiscal, and infrastructural pressures.

Evolutionary economics extends this reasoning by interpreting resilience as a dynamic, path-dependent process of variation, experimentation, learning, selection, and retention across institutional and organizational scales. Rather than restoring equilibrium, organizations and institutions respond to changing selection environments by modifying routines, recombining existing capabilities, experimenting with alternative responses, and selectively retaining practices that prove effective (Nelson and Winter 1982). Applied to regional resilience, this evolutionary perspective emphasizes resistance, recovery, reorientation, and renewal as interrelated processes shaped by historically accumulated innovation capacities, governance structures, institutional diversity, and regional development trajectories (Simmie and Martin 2010). From this perspective, resilience is inherently path-dependent, as the range of responses available to a system under shock is conditioned by capabilities, relationships, institutions, and routines historically accumulated before disruption.

This evolutionary interpretation is particularly relevant to institutional resilience. Institutional resilience refers to the capacity of governance systems to preserve essential functionality while modifying, recombining, and, where necessary, creating institutional rules, organizational routines, and coordination arrangements in response to changing conditions. The concept involves more than institutional persistence. Resilient governance systems must mobilize distributed knowledge and resources, generate adaptive variation, incorporate feedback, reorganize institutional relationships, and selectively stabilize effective responses in rapidly changing environments. Institutional resilience consequently combines continuity with adaptive and potentially transformative change.

Resilience scholarship further suggests that systems may respond to disturbance through qualitatively different yet interrelated forms of response. Bouchard's typology of resistance, adaptation, and transformation closely parallels the evolutionary processes through which institutions retain existing routines, modify organizational arrangements, and generate new developmental pathways (Bouchard 2013). Extending this perspective, Béné and Doyen recognize the "multiform" nature of resilience and conceptualize resilience outcomes (or emergence) as a combination of different properties (or capacities), ranging from resistance to coping strategies, adaptive preference, adaptive capacity, and eventually transformability. These five types of resilience strategies (or responses), namely resistance, absorptive resilience or coping, adaptive resilience, adaptive preference, and transformation, can be placed along a continuum that reflects the different levels and types of responses the system will adopt to withstand the impacts of shocks (or stress) (Béné and Doyen 2018). The scholars use the word "continuum" deliberately to recognize that the boundaries between those strategies are disputable, case-specific, and subject to interpretation. At one end of the continuum, resistance reflects the retention of core institutional routines, organizational structures, and governance functions with little or no change. Absorptive resilience, or coping, involves temporary adjustments that buffer the immediate effects of disruption while preserving the underlying structure and operating logic of the system. However, when the shock exceeds the system's absorptive capacity, the system requires an adaptive strategy. Adaptive resilience involves more substantial but generally incremental changes in institutional arrangements, decision-making processes, and organizational routines, enabling the system to continue functioning under altered conditions without major qualitative changes in how it operates (Nelson et al. 2007). Adaptive preference refers to a reflexive process through which actors revise their expectations, priorities, or goals in response to deteriorating circumstances, thereby adjusting the standards or constraints against which continued functioning is evaluated (Béné et al. 2014). When the changes required in response to shocks are so large that they overwhelm the system's adaptive capacity, transformation must take place to avert irreversible consequences (Béné and Doyen 2018). Transformation corresponds to Schumpeterian creative response through the emergence of fundamentally new governance structures, coordination mechanisms, and socio-economic configurations when "ecological, economic, or social structures make the existing system untenable" (Walker et al. 2004).

Resilience can be conceptualized as a combination of responses that vary greatly in nature and intensity and lead to different outcomes (Walker et al. 2004). These responses represent different forms and intensities of institutional response to shock that may coexist across governance functions. Under prolonged defensive-war conditions, different responses may coexist within the same regional governance system where some functions may continue through existing routines, others may rely on temporary coping mechanisms, while still others require substantial adaptation or transformative restructuring. Therefore, wartime resilience emerges from a portfolio of differentiated responses rather than from a single uniform strategy.

Building on these perspectives, the WIRF conceptualizes WIR as an emergent system-level outcome of adaptive governance operating through the CMIE under defensive-war selection pressure, reflected in the regional governance system's realized ability to preserve and adapt essential functionality. WIR reflects an oblast-centered regional governance system's capacity to preserve essential institutional functionality while adapting and, where necessary, transforming governance arrangements in response to recurrent disruption. The concept emerges through

continuous processes of adaptive variation, experimentation, operational feedback, organizational learning, resource recombination, coordination, selection, retention, and institutionalization across interconnected civilian, military, economic, technological, civic, and governance domains.

This interpretation distinguishes WIR from both adaptive governance and the CMIE itself. Adaptive governance constitutes the dynamic coordination process through which distributed capabilities are mobilized, recombined, and selectively institutionalized, while the CMIE provides the evolving relational infrastructure through which heterogeneous public, military, private, academic, civic, and transnational actors interact. WIR is the emergent outcome of these interactions at the level of the regional governance system. In this sense, no single organization, capability, or governance function produces resilience independently; rather, resilience arises from the capacity of interconnected actors and institutions to coordinate differentiated responses while sustaining essential regional functionality.

Within the WIRF, WIR is expressed through the regional governance system's capacity to preserve, adapt, and, where necessary, transform its interdependent substantive functions under prolonged defensive-war pressure. The performance of these functions depends not only on the capacities of individual governance domains but also on the quality of the relationships connecting them, including information flows, coordination mechanisms, feedback channels, redundancy, and the ability to mobilize and recombine resources under changing wartime conditions. WIR consequently represents neither simple resistance to disruption nor restoration of a pre-war equilibrium, but the emergent capacity of a regional governance system to remain functional while continuously adapting its institutional configuration under prolonged defensive-war pressure.

Taken together, these theoretical perspectives suggest that Ukraine’s capacity to remain resilient under an extreme and prolonged war shock rests not on static resistance alone, but on the continuous generation, selection, scaling, and institutional retention of creative responses. This proposition provides the central theoretical premise of the WIRF developed in the following section. The framework specifies the system whose resilience is assessed, the defensive-war selection pressure against which resilience is tested, the antecedent capacities on which adaptation draws, the CMIE through which heterogeneous actors are connected, the adaptive-governance mechanisms through which responses are coordinated, and the regional governance functions through which WIR becomes observable and empirically measurable.

3. The Wartime Institutional Resilience Framework (WIRF): An Evolutionary Adaptive Governance Framework for Civil-Military Innovation under Defensive-war Shock

3.1 The Wartime Institutional Resilience Framework: Resilience of What, to What, for What and Through What Mechanisms?

Building on the preceding theoretical foundations, the WIRF organizes these relationships into a meso-level analytical framework structured around four questions: resilience of what, to what, through what mechanisms, and for what functional purpose?

3.1.1 Resilience of what? The oblast-centered regional governance system

The resilience-bearing system within the WIRF is the oblast-centered regional governance system. In the Ukrainian context, this system is a multilevel configuration through which central government institutions, oblast and rayon state or military administrations, local self-government bodies, and territorial communities coordinate public authority, allocate resources, implement policy, and sustain essential territorial functions. This public governance core is embedded within a broader regional environment comprising businesses, universities and research organizations, infrastructure operators, digital platforms, civil society organizations, volunteer networks, military actors, and international partners.

The regional governance system is therefore broader than public administration alone. Formal public authorities retain statutory responsibility for decision-making, regulation, budgeting, public-service provision, and territorial coordination, but their capacity to fulfill these responsibilities increasingly depends on interaction with heterogeneous actors who possess distributed knowledge, technological capabilities, material resources, social legitimacy, and operational experience. Under defensive-war conditions, these interdependencies become particularly consequential as civilian, military, economic, technological, humanitarian, and administrative domains become increasingly interconnected.

Regional governance becomes operational through a set of substantive governance functions. In general terms, these include strategic planning, economic regulation, social protection and public-service provision, budgetary and financial management, spatial and infrastructural development, environmental protection, and coordination and

control. These functions define the principal domains through which public authority organizes territorial development and collective well-being. They constitute the substantive object whose continuity, adaptation, and transformation are at stake when the regional governance system is exposed to severe disruption.

However, the WIRF does not assume that the full universe of regional governance functions can be captured empirically in a single index. Instead, the empirical component of this study focuses on a selected set of wartime governance functionality domains through which institutional performance under prolonged defensive-war pressure becomes observable, namely digital coordination, administrative resource allocation, fiscal continuity, socio-economic mobilization, and labor-market and human-capital adaptation. These functionality domains are analytically related to the broader responsibilities of regional governance but should not be interpreted as an exhaustive taxonomy of regional-governance functions. Rather, they constitute observable manifestations of the capacity of regional governance systems to remain functional and adapt during war.

3.1.2 Antecedent regional conditions: what capacities does the system bring into the shock?

Regional governance systems do not enter defensive war with identical adaptive capacities. The WIRF therefore begins with a set of antecedent regional conditions that reflect historically accumulated institutional, economic, technological, social, human-capital, infrastructural, territorial, and relational characteristics. These conditions are produced by long-term regional development trajectories, governance arrangements, RISs, institutional learning, economic structures, and patterns of social and organizational interaction.

Antecedent conditions contain elements of both adaptive capacity and vulnerability. Following Cutter et al., resilience and vulnerability are not treated as simple opposites (Cutter et al. 2008). A region may possess strong capabilities in one domain while remaining highly exposed to another. Strong digital infrastructure, diversified economic activity, administrative competence, fiscal capacity, dense organizational networks, or high levels of civic mobilization may enhance adaptive potential, while infrastructure dependence, demographic decline, weak institutional capacity, limited fiscal resources, or territorial exposure may increase vulnerability.

These conditions are also path-dependent. National policies, state regulation, decentralization arrangements, fiscal relations, and broader national development trajectories influence regional capacities, while regional institutions and innovation systems generate territorially differentiated patterns of knowledge creation, resource mobilization, coordination, and adaptive capability (Capello 2015; Martinelli et al. 2013; Boschma and Martin 2007; Martin et al. 2016; Webber et al. 2018). National policies and institutional arrangements influence regional resource endowments and constraints, while regional governance and innovation systems generate territorially differentiated capacities for learning, coordination, and adaptation (Hassink and Klaerding 2011; Cooke 2013). The WIRF therefore treats regional resilience not as a capacity created by war itself but as a dynamic outcome partly conditioned by capabilities and vulnerabilities accumulated before the war shock.

Ukraine's decentralization reforms illustrate the importance of these antecedent institutional conditions (Brovko 2024). For example, they show that increased local fiscal autonomy, clearer administrative mandates, and enhanced municipal capacity strengthened decentralized crisis-response capabilities. These reforms did not predetermine wartime resilience, but they altered the institutional resources and coordination options available to regional and local authorities as the full-scale defensive war intensified.

3.1.3 Resilience to what? Defensive war as an evolving selection environment

WIR is assessed against prolonged defensive-war selection pressure. Unlike a discrete hazard event, defensive war constitutes a continuous, multidimensional, and spatially uneven shock. Regional governance systems may face varying combinations of frontline proximity, missiles, drone, and artillery attacks, energy infrastructure destruction, population displacement, fatalities, economic disruption, fiscal pressure, administrative strain, labor shortages, logistical disruption, and persistent uncertainty.

Within the WIRF, conflict severity is therefore not a component of resilience itself. It represents the external selection pressure against which resilience is tested. Defensive-war pressure disrupts established organizational routines, alters resource constraints and policy priorities, exposes institutional vulnerabilities, and increases the value of experimentation, coordination, learning, and rapid resource recombination. Because the intensity and composition of these pressures vary considerably across Ukrainian regions and over time, WIR is inherently territorially differentiated.

This distinction allows the framework to separate the severity of the challenge from the regional governance system's capacity to respond. Two regions exposed to comparable levels of wartime pressure may display different resilience outcomes because their antecedent capacities, organizational relationships, adaptive-governance processes, and abilities to mobilize external resources differ substantially.

3.1.4 Through what mechanisms? Adaptive governance operating through the CMIE

Exposure to wartime pressure does not automatically generate resilience. The central mechanism of the WIRF is adaptive governance, understood as the dynamic coordination process through which the regional governance system senses changing conditions, integrates feedback, mobilizes and recombines distributed resources, coordinates heterogeneous actors, experiments with alternative responses, selects and scales effective solutions, and retains successful organizational and institutional practices.

Adaptive governance does not constitute an additional substantive regional-governance function. Instead, it operates across existing governance functions, enabling them to be maintained, reorganized, or transformed as wartime conditions change. Its relationship with regional governance functionality is therefore cross-cutting. Fiscal continuity, for example, may depend on information flows, intergovernmental coordination, resource reallocation, experimentation with emergency financial arrangements, and the institutionalization of successful practices. Labor-market adaptation may similarly require sensing emerging skill shortages, coordinating public and private actors, reallocating human resources, and scaling effective training or employment responses.

These adaptive-governance processes operate through the CMIE developed in Section 2.2. The CMIE provides the evolving relational infrastructure connecting public authorities, military actors, businesses, technology firms, universities, civil society organizations, volunteer networks, infrastructure operators, affected communities, and transnational partners. Through these relationships, knowledge, information, technologies, financial resources, operational experience, and organizational capabilities can circulate across institutional and sectoral boundaries.

The relationship between adaptive governance and the CMIE is therefore complementary but analytically distinct. The CMIE provides relational architecture; adaptive governance provides the operating logic through which this architecture is mobilized. Together, they enable distributed adaptive capacities to be converted into coordinated responses to wartime selection pressure.

Within the WIRF, these adaptive-governance processes can be summarized through six interconnected mechanisms: (1) threat sensing and feedback integration; (2) cross-sector and civil-military coordination; (3) resource mobilization and recombination; (4) decentralized experimentation and adaptive problem-solving; (5) selection, scaling, and diffusion of effective responses; and (6) institutional retention and reconfiguration. These processes correspond to the evolutionary logic of variation, selection, and retention developed in the preceding theoretical sections and connect localized experimentation with broader institutional adaptation.

3.1.5 For what? Preserving and reconfiguring essential governance functionality

Resilience in the WIRF aims to safeguard key regional governance functions rather than maintaining all pre-war institutional setups. It permits adjustments in organizational structures, routines, priorities, and relationships when current arrangements prove ineffective under defensive-war conditions.

WIR may therefore involve resistance, absorption, adaptation, and transformation simultaneously. The relevant criterion is not whether the institutional system remains unchanged, but whether it continues to perform essential governance functions while responding to altered environmental conditions. In this sense, institutional continuity and institutional change are not contradictory. Continuity concerns preserving essential functionality; adaptation and transformation concern the means by which that functionality is sustained under changing conditions.

WIR as the emergent system-level outcome

The systemic character of WIR means that resilience depends not only on the strength of individual capacities but also on the quality of relationships among them. Information flows, feedback mechanisms, coordination channels, institutional trust, redundancy, cross-sector connectivity, and the capacity to recombine resources determine whether distributed capabilities translate into collective adaptive performance. Consequently, a region possessing substantial resources may remain vulnerable if those resources cannot be effectively coordinated, while a region with more limited resources may demonstrate considerable adaptive capacity when institutional and relational connections enable rapid mobilization and recombination.

The WIRF therefore conceptualizes the relationship among its principal elements as follows: antecedent regional conditions define the historically accumulated capacity and vulnerability with which the regional governance system enters the shock; defensive war generates external selection pressure; the CMIE connects distributed actors and capabilities; adaptive governance mobilizes, coordinates, experiments with, selects, and institutionalizes responses; these processes sustain and reconfigure regional governance functionality; and WIR emerges as the resulting system-level capacity to remain functional while adapting under prolonged defensive-war pressure.

Fig. 1 summarizes the evolutionary architecture of the WIRF, showing how historically accumulated regional conditions and pre-existing Regional Innovation Systems are exposed to defensive-war selection pressure, reconfigured through Civil-Military Innovation Ecosystems and adaptive governance, and translated into differentiated institutional responses, observable wartime functionality, and potentially new regional development paths.

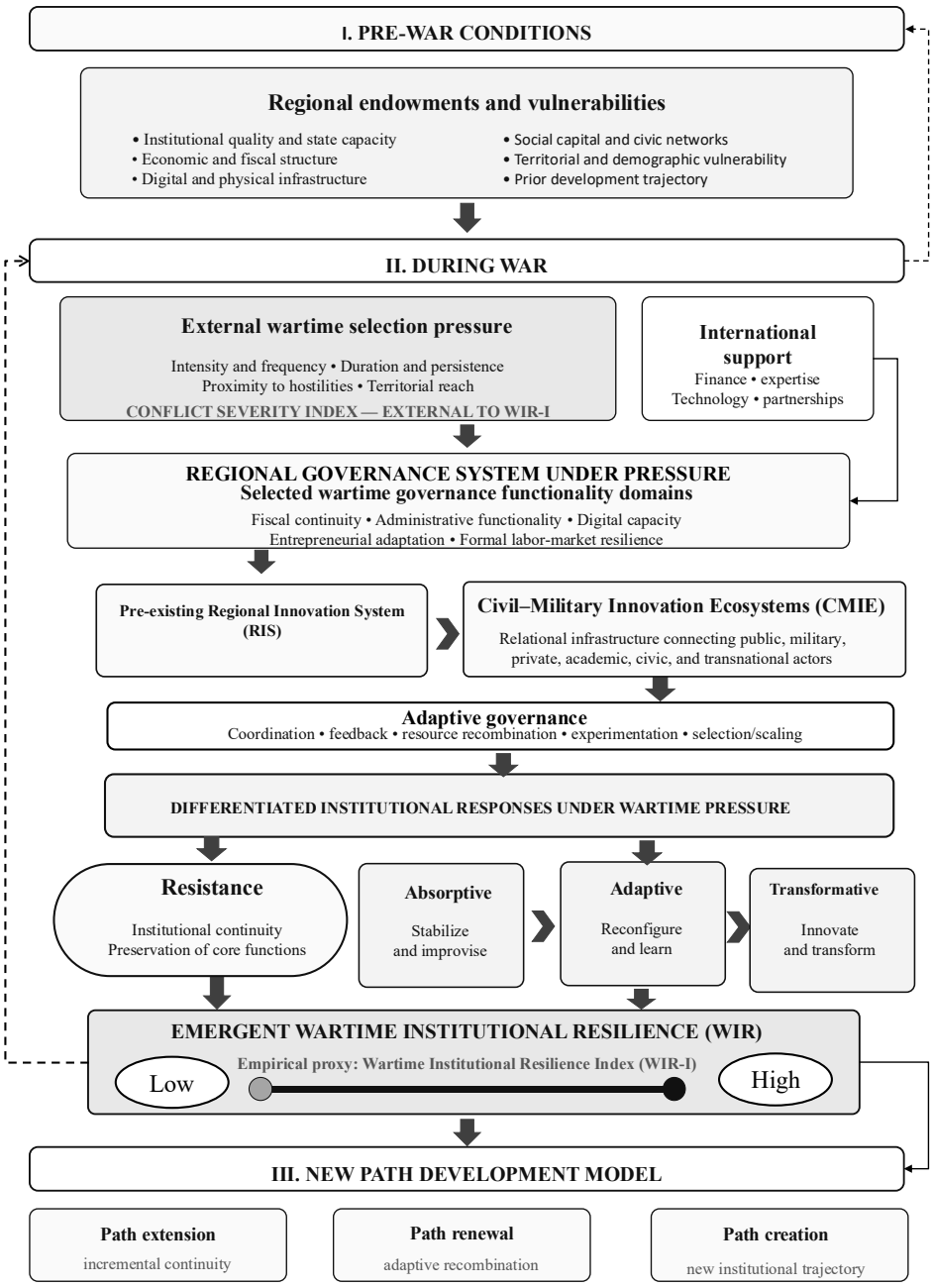


Fig. 1. Wartime Institutional Resilience Framework (WIRF): From Pre-War Regional Capacities to Wartime Adaptation and New Path Development. *Note: Developed by the authors*

Importantly, this relationship is recursive rather than linear. Successful wartime responses may be retained and institutionalized, thereby altering future antecedent conditions. Learning, accumulated experience, new

organizational routines, strengthened networks, digital capabilities, innovation infrastructures, and enhanced external credibility may increase subsequent adaptive capacity. Conversely, prolonged depletion, institutional failure, corruption, demographic erosion, or infrastructure destruction may weaken future resilience. WIR is therefore both an outcome of previous adaptation and a condition shaping future regional adaptive capacity.

This framework provides the basis for identifying the structural capacities and governance conditions that strengthen or constrain wartime adaptation and for operationalizing WIR empirically across Ukrainian regions. The following analysis therefore distinguishes between external wartime selection pressure, antecedent and enabling capacities, adaptive-governance mechanisms, observable wartime governance functionality, and WIR as the emergent regional outcome.

The WIRF is subject to several analytical boundary conditions. First, it is developed specifically for prolonged defensive-war environments in which regional governance systems are exposed to continuous, multidimensional, and spatially uneven selection pressure. Although elements of the framework may be relevant to other severe disruptions, its applicability beyond defensive-war conditions requires further theoretical and empirical validation. Second, the WIRF focuses on the meso-level, with the oblast-centered regional governance system as its primary unit of analysis, while recognizing that regional resilience is embedded within interacting micro- and macro-level processes. Third, WIR is analytically distinguished from societal, economic, military, and other forms of resilience, although these remain functionally interconnected. Finally, regional resilience is shaped not only by endogenous regional capacities but also by broader national policies, regulatory and fiscal arrangements, and international support, which constitute important external conditions influencing the adaptive possibilities available to regional governance systems.

3.2 Hypotheses Development

The WIRF conceptualizes Wartime Institutional Resilience (WIR) as an emergent regional outcome shaped by defensive-war selection pressure, selected functionality domains, and the regional governance system's capacity to sustain essential functionality. The formal hypotheses therefore examine two relationships: (1) the association between conflict severity and WIR; and (2) the association between selected wartime governance functionality domains and WIR.

H1. Conflict severity and WIR: Higher conflict severity is associated with lower observed wartime institutional resilience, as measured by the WIR-I, across Ukrainian oblast-quarter observations. Within the WIRF, conflict severity represents external wartime selection pressure rather than a component of resilience. Greater exposure to military violence, fatalities, infrastructure disruption, displacement, and administrative strain is expected to be associated with greater difficulty in preserving regional governance functionality.

WIR becomes observable through the ability of regional governance systems to maintain and adapt essential functions under prolonged disruption. The empirical analysis focuses on five measurable wartime functionality domains.

H2. Fiscal continuity and WIR: Regions with stronger fiscal continuity exhibit higher WIR. Fiscal continuity reflects the capacity of public-finance systems to sustain revenues, budget execution, public services, and emergency response.

H3. Administrative functionality and WIR: Regions with stronger administrative functionality exhibit higher WIR. Administrative functionality reflects the continued capacity of public institutions to plan, contract, procure, coordinate public spending, and deliver goods and services under wartime conditions. In this study, sampled procurement activity serves as a proxy for this dimension, indicating whether institutions remain sufficiently operational to allocate resources, complete public-sector transactions, respond to emergency needs, and support recovery-related activities.

H4. Digital capacity and WIR: Regions with stronger digital capacity exhibit higher WIR. Digital capacity supports public-service continuity, information exchange, administrative coordination, digital procurement, fiscal administration, public communication, and cybersecurity when conventional administrative channels are disrupted.

H5. Entrepreneurial adaptation and WIR: Regions with stronger entrepreneurial adaptation exhibit higher WIR. Entrepreneurial adaptation captures the capacity of regional socio-economic systems to sustain formal business activity, self-employment, and economic participation while adjusting to wartime conditions.

H6. Labor-market resilience and WIR: Regions with stronger formal labor-market resilience exhibit higher WIR. Labor-market resilience reflects the capacity of regional labor-market systems to sustain formal economic

participation and adjust to displacement, mobilization, demographic losses, and changing labor demand. Because the empirical measure relies on registered unemployment, it captures formal rather than total labor-market stress.

Together, H1 examines wartime selection pressure, while H2-H6 examine whether stronger performance across selected wartime governance functionality domains is associated with stronger resilience outcomes. Because the indicators used in H2-H6 also contribute to the WIR-I, the corresponding empirical models use reduced versions of the index that exclude the tested component, thereby avoiding mechanical part-whole correlation.

3.3 From WIRF to Empirical Operationalization

The multidimensional and systemic nature of WIR creates an inherent measurement challenge. As Carpenter et al. emphasize, measuring resilience requires explicitly specifying both resilience of what and resilience to what (Carpenter et al. 2001). Within the WIRF, the resilience-bearing system is the oblast-centered regional governance system, while the relevant disturbance is prolonged and spatially uneven defensive-war selection pressure. Therefore, WIR cannot be fully captured by a single administrative or economic indicator, as it reflects the ability of linked regional systems to maintain and adjust vital governance functions across areas.

A composite-indicator approach is appropriate when a multidimensional theoretical construct must be synthesized into an interpretable empirical measure. This approach aligns with the OECD/JRC framework for composite indicators (Nardo et al. 2008) and with resilience-measurement scholarship that emphasizes the interdependence among multiple system dimensions (Béné 2013; Gall 2013; Mitchell 2013; Winderl 2014). This multidimensional perspective is particularly relevant in wartime, when regional systems may perform unevenly across functional domains - for example, maintaining fiscal operations while experiencing administrative strain, business disruption, or labor-market stress.

Accordingly, this study operationalizes WIR through a first-generation Wartime Institutional Resilience Index (WIR-I) comprising five observable wartime governance domains: fiscal continuity, administrative functionality, digital capacity, entrepreneurial adaptation, and formal labor-market resilience. Fiscal continuity captures the preservation of public-finance functionality; administrative functionality reflects ongoing resource allocation and procurement activity; digital capacity captures the continuity and adaptive use of digital governance capabilities; entrepreneurial adaptation reflects the maintenance and reorganization of formal economic activity; and labor-market resilience captures the capacity of the formal labor-market system to absorb and adjust to wartime stress. Together, these domains provide an empirically observable representation of selected manifestations of regional institutional functionality under defensive-war pressure.

Within the WIRF, fiscal continuity represents the financial governance functionality domain through which public institutions mobilize, allocate, and sustain the resources necessary for wartime governance. Fiscal continuity ensures that governance systems possess the financial capacity to maintain revenue collection, execute budgets, finance public services, support emergency response, and preserve institutional functionality under prolonged wartime disruption.

Public procurement provides an observable domain of administrative functionality through which public institutions allocate resources and sustain administrative processes under wartime conditions. Ukraine’s digitalized public procurement system, especially through Prozorro, illustrates how digital governance is translated into institutional functionality, enabling public institutions to allocate resources, coordinate actors, and sustain essential administrative processes under wartime conditions.

Within WIRF, digital capacity refers to the regional governance system’s ability to use digital infrastructures, platforms, and organizational capabilities to sustain service delivery, information exchange, administrative coordination, and institutional adaptation under wartime disruption. Through these technologies, digitalization creates technological capacity: an integrated system of digital platforms, organizational routines, institutional arrangements, and coordination mechanisms that enables public institutions, businesses, and civil society organizations to preserve functionality, adapt rapidly, and continue delivering essential services despite infrastructure destruction, population displacement, logistics breakdowns, blackouts, and security disruptions. Digital tools can also help Ukrainian businesses respond to wartime disruption and support recovery (OECD 2024).

Entrepreneurial adaptation represents the socio-economic functionality domain through which formal business activity, self-employment, and decentralized economic initiative adjust to wartime disruption. Civic and volunteer mobilization constitutes a related but analytically distinct form of adaptive capacity within the broader WIRF. During Ukraine's defensive war, civil society organizations, volunteer networks, charitable initiatives, local communities, small businesses, and informal support systems have played a critical role in sustaining both societal resilience and institutional functionality. As Reznikova and Korniievskyi argue, Ukraine's resilience has been reinforced by civic identity, social trust, cooperation among public authorities, businesses, and civil society, and

widespread practices of self-organization, mutual assistance, and volunteerism (Reznikova and Korniievskyi 2024). These networks have provided flexible problem-solving capacity through humanitarian logistics, evacuation support, shelter coordination, psychological assistance, aid distribution, digital services, and community-level crisis response, thereby expanding society's capacity to respond flexibly to wartime disruption.

Within the WIRF, labor-market resilience represents the human-capital governance functionality domain through which regional economies preserve workforce availability, adapt employment structures, and sustain productive capacity under wartime disruption. Unlike entrepreneurial adaptation, which reflects decentralized economic initiative, labor-market resilience captures the ability of workers, employers, and public employment institutions to adjust to demographic losses, displacement, mobilization, changing skill demands, and evolving economic conditions while maintaining regional labor markets.

To make the relationship between the theoretical WIRF and its empirical operationalization explicit, Table 1 maps the framework's principal constructs onto their analytical roles and corresponding empirical treatment. The table distinguishes between the external selection pressure against which resilience is assessed, the observable functionality domains incorporated into the WIR-I, broader relational and governance mechanisms that remain theoretical in the present specification, and supplementary regional innovation evidence used to contextualize antecedent and relational capacity without entering the WIR-I itself.

Table 1. From WIRF Theory to Empirical Operationalization

WIRF construct	Theoretical role	Empirical representation	Empirical treatment
Antecedent regional conditions	Historically accumulated adaptive capacity/vulnerability	Partially observed; not comprehensively measured	Theoretical/contextual
Defensive-war selection pressure	External pressure against which resilience is tested	Conflict Severity Index (CSI)	Explanatory variable, H1
Fiscal continuity	Observable wartime governance functionality	Fiscal indicator	WIR-I component, H2
Administrative functionality	Observable wartime governance functionality	Procurement/resource-allocation indicator	WIR-I component, H3
Digital capacity	Wartime functionality and enabling adaptive capacity	Regional digitalization indicator	WIR-I component, H4
Entrepreneurial adaptation	Socio-economic functionality and decentralized adaptive capacity	Formal entrepreneurial/FOP activity	WIR-I component, H5
Formal labor-market resilience	Human-capital and labor-market functionality	Registered unemployment burden, reverse coded	WIR-I component, H6
Regional innovation-system capacity	Antecedent and relational capacity for learning, experimentation, and cooperation	Share of innovation-active enterprises and innovation-cooperation statistics, 2018-2024	Supplementary descriptive analysis; not included in WIR-I
Adaptive governance	Cross-cutting coordination mechanism	Not directly observed	Theoretical mechanism
CMIE	Relational infrastructure through which adaptive governance operates	Not directly observed	Theoretical construct
WIR	Emergent regional system-level outcome	Wartime Institutional Resilience Index (WIR-I)	Dependent/outcome measure

The WIR-I should not be interpreted as an exhaustive measure of all theoretical components of the WIRF. The broader framework also incorporates relational and processual mechanisms - including adaptive governance, CMIE connectivity, innovation, civic mobilization, learning, governance integrity, and international support - that cannot all be measured consistently at the oblast level with available data. The WIR-I therefore constitutes a first-generation empirical proxy for observed wartime regional governance functionality, while the broader WIRF provides the theoretical explanation of how such functionality is generated, coordinated, and sustained.

The construction, normalization, directional coding, and aggregation of the WIR-I are described in the Data and Methodology section.

4. Data and Methodology

4.1 Research Design

This study develops and applies a first-generation empirical operationalization of the Wartime Institutional Resilience Framework (WIRF) via the Wartime Institutional Resilience Index (WIR-I) to assess the functionality of regional governance across Ukrainian oblasts during prolonged defensive-war conditions from 2022 to 2025. The empirical design integrates composite-index construction, spatial and component-level analyses, and multivariate regression models.

The analysis proceeds in five stages. First, five observable wartime governance functionality domains - fiscal continuity, administrative functionality, digital capacity, entrepreneurial adaptation, and formal labor-market resilience - are operationalized using regional administrative and socioeconomic data. Second, the underlying indicators are directionally coded, standardized, and aggregated into domain-level sub-indices and then into the WIR-I, yielding a multidimensional empirical proxy for observed regional governance functionality under wartime pressure. Third, spatial and component-level analyses examine territorial variation and heterogeneous functionality profiles across oblasts. Fourth, regression models test H1-H6 by assessing the association between defensive-war selection pressure and WIR and by estimating component-excluded models for the five functionality-domain hypotheses. Most specifications use the harmonized oblast-quarter panel; formal labor-market resilience is tested separately at the source-faithful oblast-year level because registered-unemployment observations are not independently observed at the quarterly frequency. Fifth, a supplementary descriptive analysis of regional innovation activity and innovation cooperation contextualizes antecedent regional innovation-system capacity and wartime reconfiguration. These supplementary innovation measures are not incorporated into the WIR-I and do not constitute additional formal hypotheses.

4.2 Unit of Analysis, Sample, and Temporal Structure

The primary spatial unit of analysis is the Ukrainian oblast, consistent with the WIRF's meso-level orientation. The study covers 2022-2025 and uses the oblast-quarter as the preferred temporal unit. The final harmonized no-Crimea analytical panel comprises 384 oblast-quarter observations across 24 analytical oblasts and 16 consecutive quarters. To operationalize the WIRF, we constructed an integrated oblast-level analytical dataset by assembling, cleaning, harmonizing, and transforming data from multiple administrative and complementary sources.

Indicators available at quarterly frequency retain their observed quarterly variation, whereas annual or source-level contextual indicators are assigned to quarterly rows for panel harmonization and are not interpreted as quarter-specific changes. Registered-unemployment data constitute an important exception: the underlying source provides annual/reporting-period endpoint observations rather than an independently observed quarterly series. These values may appear in quarterly panel rows for index harmonization, but the primary H6 regression uses one source-faithful observation per oblast-year to avoid pseudo-replication.

Crimea is retained in selected geographic visualizations for territorial completeness but is excluded from the analytical WIR-I sample because comparable wartime institutional data are unavailable. Kyiv City is treated separately where source coverage requires it, because some official datasets report it separately from Kyiv oblast. The main regression record relies on the harmonized 24-oblast analytical panel, with model-specific frequency adjustments where required by the source structure.

4.3 Data Sources and Variable Operationalization

The five WIR-I domains represent selected observable manifestations of wartime regional governance functionality identified through the WIRF. Their operationalization reflects both the framework's theoretical architecture and the availability of sufficiently comparable oblast-level data for 2022-2025.

4.3.1 Fiscal Continuity

Fiscal continuity is operationalized primarily using OpenBudget BOOST data published by the Ministry of Finance of Ukraine, covering quarterly executed fiscal flows for local budgets from 2022Q1 to 2025Q4. The broader fiscal layer includes executed local-budget revenue, expenditure, tax revenue, official transfers, own-source revenue, own-source revenue share, tax-revenue share, an expenditure-to-revenue ratio, and a fiscal-balance proxy. For WIR-I construction, the fiscal-continuity sub-index is the equal-weighted mean of four directionally aligned standardized

indicators: approved-plan revenue execution, own-source revenue share, tax-revenue share, and reverse-coded expenditure-to-revenue pressure. When all four indicators are observed, each contributes 25 percent to the fiscal sub-index. The approved-plan revenue-execution measure is annual and is assigned across the four quarters of the corresponding year for panel compatibility, whereas the remaining fiscal ratios vary quarterly.

Fiscal continuity is interpreted as the capacity of local public-finance systems to remain operational under wartime pressure, rather than as the absence of fiscal stress. A heavily exposed oblast may experience declining own-source revenues or increased transfer dependence while nevertheless preserving budget execution and financing essential public functions. Higher fiscal-continuity scores therefore indicate stronger observed preservation of public-finance functionality relative to other oblasts in the sample.

4.3.2 Administrative Functionality

To operationalize administrative functionality, we constructed an oblast-quarter dataset from sampled public-procurement records. The broader procurement layer includes tender counts, procurement value, average tender value, tender-status measures, and derived log-transformed indicators. For WIR-I construction, the Administrative Functionality sub-index is the equal-weighted mean of four standardized measures: log-transformed total tender count, log-transformed procurement value, tender completion rate, and reverse-coded cancellation rate. Logarithmic transformations reduce the influence of the highly skewed distributions of procurement counts and values, while directional coding ensures that higher sub-index values consistently reflect stronger observed administrative continuity.

Procurement serves as a proxy for administrative functionality because successful contracting depends on functioning legal, financial, managerial, logistical, vendor, and human-capital systems. Continued procurement therefore provides an observable signal that public institutions retain at least partial capacity to allocate resources and implement administrative decisions.

The procurement dataset is sample-based and should not be interpreted as a complete census of Ukrainian public procurement. Accordingly, high procurement volume is not treated as equivalent to high resilience. Elevated activity may reflect administrative capacity, but it may also result from emergency demand, reconstruction, humanitarian needs, repair costs, defense-related requirements, regional scale, or the concentration of public institutions. Conversely, low observed procurement may reflect reduced demand, occupation, security constraints, displacement, or incomplete coverage. Monetary-scale statements are reported only when the original procurement-value unit has been verified in the source pipeline; the standardized H3 measure itself is based on log-transformed and standardized procurement values rather than raw monetary magnitudes.

4.3.3 Digital Capacity

Digital capacity is measured using the Digital Transformation Index of Ukrainian Regions (DTI) published by the Ministry of Digital Transformation for 2022-2025. The DTI tracks 126 indicators that provide a broad assessment of regional digital maturity, including digital public services, infrastructure, governance practices, digital skills, and implementation of national digital-transformation objectives (Ministry of Digital Transformation of Ukraine 2025; European Business Association 2026). The Diia. Digital Community platform provides access to regional and community digital transformation indices and supports coordination among local digital leaders (Ministry of Digital Transformation of Ukraine n.d.-a).

Because the DTI methodology and reporting structure changed during the study period, raw annual scores are not assumed to be fully comparable longitudinally. The analysis therefore preserves the original score while constructing a common 0-1 transformation, a within-year standardized score, and a within-year percentile rank. The within-year standardized measure is used in statistical analysis because it evaluates each oblast relative to others assessed under the same annual methodology, while percentile ranks support descriptive and spatial visualization.

Annual DTI observations are assigned to the four quarters of the corresponding year. Digital capacity is therefore interpreted as an annual contextual regional capacity rather than a quarterly transaction-level variable. Accordingly, the analysis interprets the DTI primarily as a measure of cross-regional digital capacity within each year and does not infer longitudinal change directly from differences in raw annual DTI scores. To verify that repetition across quarterly rows does not drive inference, the principal robustness check for H4 re-estimates the digital specification at the source-consistent oblast-year frequency.

4.3.4 Entrepreneurial Adaptation

To operationalize entrepreneurial adaptation, we constructed a regional FOP dataset by integrating several complementary sources on individual entrepreneurs (*Fizychna osoba-pidpryiemets*, FOP), a widely used Ukrainian legal form for individual business and self-employment activity. Because a consistent oblast-quarter FOP series is not available for the full 2022-2025 period, the dataset combines regional FOP-opening dynamics for March 2022-December 2024 with quarterly oblast-level openings and closures for 2025, allowing us to construct net openings,

openings per 10,000 residents, net openings per 10,000 residents, and closure ratios. National monthly FOP data are used only as contextual evidence of broader wartime entrepreneurial trends.

Continued FOP formation and formal entrepreneurial activity are interpreted as observable manifestations of decentralized socioeconomic adaptation. Under wartime conditions, individuals and small businesses may respond to disrupted markets, changing demand, displacement, supply constraints, and emerging civilian or military needs by establishing new ventures, reallocating resources, modifying business models, and sustaining formal market participation. Such activity contributes to decentralized experimentation and resource recombination and, therefore, to the distributed generation of adaptive variation emphasized by the WIRF. A particularly dynamic contemporary expression of this process in Ukraine is the rapid expansion of the DefTech sector, where military-technology startups develop and adapt solutions for the Armed Forces and other state security needs. The expansion of DefTech illustrates how decentralized entrepreneurial experimentation can generate adaptive variation that is subsequently selected, scaled, and integrated into wider civil-military innovation networks. However, FOP formation is not interpreted as a direct measure of DefTech, technological innovation, or startup activity; rather, FOP dynamics provide a broader proxy for entrepreneurial experimentation, formal economic participation, and decentralized adaptive capacity under wartime disruption.

Because the underlying FOP sources differ in temporal coverage and form, the final entrepreneurial-adaptation measure is treated as a regional 2022-2025 composite rather than as a genuinely quarterly series. Its representation in the quarterly analytical panel supports harmonization with the other WIR-I domains but should not be interpreted as independent quarter-to-quarter entrepreneurial variation. A source-level 24-oblast cross-sectional specification is therefore used as the principal robustness check for H5.

4.3.5 Formal Labor-Market Resilience

Formal labor-market resilience is operationalized through registered unemployment burden, which provides an observable measure of formal labor-market stress under wartime conditions. Because comprehensive and consistently comparable oblast-level measures of employment and labor-force adjustment are unavailable for the full study period, the indicator is treated as a proxy for one dimension of labor-market functionality rather than as a comprehensive measure of labor-market resilience.

The labor-market dataset is constructed from registered unemployment data reported by the State Employment Service of Ukraine. The primary measure is the number of registered unemployed persons at the end of the reporting period. To improve comparability across oblasts of different sizes, the raw count is normalized per 10,000 residents using a stable 2022 baseline population denominator. Registered unemployment burden is treated as a negative indicator and reverse-coded before inclusion in the WIR-I, so that a lower recorded burden corresponds to a higher formal labor-market resilience score. Because the denominator is fixed within each oblast over time, this measure is interpreted as a comparative administrative burden normalized to a common baseline population rather than as a contemporaneous wartime unemployment incidence rate.

The temporal structure of the source differs from the panel's genuinely quarterly components. The 2022 and 2023 observations are January-September reporting endpoints, whereas the 2024 and 2025 observations are January-December endpoints. Repeated values across quarterly rows are used only for index construction and panel harmonization and are not treated as evidence of quarterly labor-market movement. Accordingly, the primary H6 test is estimated at the oblast-year level using one source-faithful labor observation per oblast-year, with the reduced WIR-I and conflict measure aggregated to the corresponding annual level.

This interpretation requires caution under wartime conditions. Registered unemployment includes only individuals formally recorded by the State Employment Service and therefore does not fully capture those who have migrated abroad, withdrawn from the labor force, entered informal employment, joined the armed forces, relocated without registering, or remained in occupied or heavily disrupted territories where employment services may be inaccessible. Registration levels also depend on regional institutions' capacity to maintain employment-service access and administrative reporting. Consequently, a lower registered unemployment burden may indicate stronger formal labor-market conditions, but it may also reflect displacement, non-registration, or limited administrative accessibility. The indicator is therefore interpreted comparatively as one observable dimension of wartime regional functionality, rather than as a stand-alone measure of labor-market performance.

4.4 Construction of the Wartime Institutional Resilience Index (WIR-I)

The Wartime Institutional Resilience Index (WIR-I) synthesizes five selected wartime governance functionality domains (fiscal continuity, administrative functionality, digital capacity, entrepreneurial adaptation, and formal labor-market resilience) into a composite measure of observed regional institutional resilience. Index

construction follows a two-stage procedure in which indicators are first aggregated within each functionality domain, and the resulting domain-level sub-indices are then combined into the overall WIR-I. This structure ensures that domains represented by a larger number of raw indicators do not receive greater implicit weight in the composite index.

4.4.1 Directional coding and standardization.

Because the underlying indicators differ in scale, units of measurement, and substantive direction, all variables are directionally coded so that higher values consistently indicate stronger observed functionality. Positive-capacity indicators retain their original direction, whereas negative indicators - such as procurement cancellations, expenditure pressure where applicable, and the registered unemployment burden - are reverse-coded before aggregation.

Unless otherwise specified, directionally aligned indicators are standardized using z-scores over the relevant analytical sample. The Digital Transformation Index is an exception: because its methodology changed across years, the digital measure used in statistical analysis is standardized within year, as described in Section 4.3.3. Standardization places variables measured in different units on a common relative scale while preserving the source-specific comparability rules required for individual domains:

$$Z_{kit} = \frac{X_{kit} - \bar{X}_k}{SD_k},$$

where: X_{kit} is indicator k for oblast i in quarter t; $\bar{X}_k$ is the sample mean of indicator k; SD_k is the sample standard deviation of indicator k. Standardization places variables originally measured in different units on a common scale with a mean of zero and a standard deviation of one.

4.4.2 Construction of domain-level sub-indices

For each of the five functionality domains, the relevant standardized and directionally coded indicators are aggregated into a domain-level sub-index. Let D_{jit} denote domain j for oblast i in period t. The domain score is calculated as:

$$D_{jit} = \frac{1}{K_j} \sum_{k=1}^{K_j} Z_{kit},$$

where K_j denotes the number of available indicators assigned to domain j.

This intermediate aggregation is important because the number of empirical indicators differs across domains. Fiscal continuity and administrative functionality, for example, are represented by multiple indicators, whereas digital capacity and formal labor-market resilience rely on more concentrated measures. Constructing domain-level sub-indices before calculating the overall WIR-I prevents domains with more underlying variables from receiving disproportionate weight.

4.4.3 Overall WIR-I

The overall WIR-I is calculated as the equal-weighted average of the five domain-level sub-indices:

$$WIR - I_{it} = \frac{1}{5}\left(D_{it}^{Fiscal} + D_{it}^{Administrative} + D_{it}^{Digital} + D_{it}^{Entrepreneurial} + D_{it}^{Labor}\right).$$

Equal domain weights are used because the WIRF provides no a priori theoretical basis for assigning greater importance to one observed functionality domain than another. The equal-weighted specification also provides a transparent and replicable first-generation operationalization of the multidimensional WIR construct.

4.4.4 Rescaling and interpretation

For descriptive interpretation, mapping, and regional comparison, the composite score is rescaled to a 0-100 range using min-max normalization:

$$WIR - I_{it}^{scaled} = 100 \times \frac{WIR-I_{it} - min(WIR-I)}{max(WIR-I) - min(WIR-I)}.$$

A value of 0 therefore represents the lowest observed WIR-I value in the analytical sample and 100 the highest observed value. Intermediate values indicate the relative position of an oblast-period observation within the observed distribution. The scaled index should not be interpreted as an absolute percentage of resilience or as distance from a universal resilience threshold; it is a sample-normalized comparative measure. The final regression specifications use the 0-100 WIR-I and correspondingly rescaled reduced-index outcomes to facilitate interpretation across models, while the underlying standardized domain scores are retained for index construction, diagnostic analysis, and component profiling.

4.4.5 Treatment of missing observations

Missing wartime observations are not automatically coded as zero because data absence may reflect occupation, administrative disruption, reporting restrictions, or source limitations rather than the absence of institutional activity. A domain sub-index is calculated from the valid indicators available within that domain, and the overall WIR-I is calculated only when at least three of the five domain sub-indices are observed. The number of valid domains is retained for each observation, while regression estimation uses the complete observations required by each hypothesis-specific specification.

Finally, conflict severity is excluded from WIR-I. Consistent with WIRF, it represents the external defensive-war selection pressure against which regional resilience is assessed rather than a component of resilience itself. Its construction and empirical treatment are therefore described separately in Section 4.5.

4.5 Conflict Severity Index: External Wartime Selection Pressure

Consistent with the WIRF, conflict severity is treated as a measure of external wartime selection pressure and is therefore excluded from the WIR-I. This distinction allows the analysis to assess how regional governance systems perform under different levels of wartime exposure without defining more heavily affected regions as inherently less resilient. Conceptually, conflict severity represents the pressure environment within which regional institutions, economic actors, and governance networks must maintain and adapt their functions.

This approach is consistent with the resilience-measurement literature, which distinguishes shocks, stresses, and losses from the capacities and responses through which resilience is manifested (Béné et al. 2012; Winderl 2014). Including conflict severity within the WIR-I would conflate the intensity of external pressure with the institutional response to that pressure. This approach would limit the empirical analysis's ability to determine whether regions exposed to different levels of wartime disruption exhibit different resilience outcomes.

To operationalize this external selection environment, we constructed an oblast-quarter conflict dataset using event-level observations from the Armed Conflict Location & Event Data Project (ACLED n.d.). ACLED provides geographically and temporally referenced records of political violence, including event dates, locations, event and sub-event types, geographic coordinates, and estimated fatalities. We filtered the raw observations to Ukraine and the relevant study period, then aggregated individual events to the oblast-quarter level (ACLED n.d.).

The resulting balanced conflict panel covers 24 Ukrainian oblasts over 16 consecutive quarters, from 2022Q1 through 2025Q4. Oblast-quarter observations with no recorded ACLED conflict activity during this period are retained as genuine zero observations rather than treated as missing.

The conflict dataset captures several dimensions of wartime pressure. The CSI itself combines three indicators: conflict-event frequency, recorded fatalities, and conflict exposure. The dataset also includes supplementary measures, such as fatalities per event, log-transformed event and fatality counts, and a frontline-status indicator. These supplementary variables do not enter the CSI unless explicitly specified. Instead, they support descriptive analysis, alternative model specifications, and regression controls. This multidimensional structure allows the analysis to move beyond a binary conflict/non-conflict classification and capture variation in the intensity and reach of wartime pressure across oblasts and over time.

Appendix A details the CSI construction procedure, including component definitions, transformation rules, and weighting. Fig. 5 in Appendix A shows the spatial distribution of mean CSI values across Ukrainian oblasts and the weekly composition of political violence events recorded by ACLED.

Accordingly, the CSI represents the intensity and multidimensional character of defensive-war selection pressure rather than resilience itself. Separating the CSI from the WIR-I preserves the analytical distinction between the external pressure imposed on a regional governance system and the institutional functionality maintained under that pressure.

4.6 Spatial and Component-Level Analysis

Spatial and component-level analyses examine how WIR varies across Ukrainian oblasts and across the five internal domains of the WIR-I. Whereas the regression analysis estimates average statistical relationships, these descriptive analyses reveal territorial heterogeneity, mixed functionality profiles, and regional configurations that may not be evident from aggregate coefficients alone.

First, average WIR-I scores for 2022-2025 are mapped by oblast to visualize the territorial distribution of observed wartime institutional resilience. The map is used to identify spatial concentration, regional variation, and potential outlier cases. It is not interpreted as a binary classification of "successful" and "failed" regions, but as a comparative representation of observed regional governance functionality under wartime pressure.

Second, a conflict–resilience scatterplot compares average Conflict Severity Index values with average WIR-I scores across oblasts. The plot is divided into four analytical configurations: low conflict/high WIR-I, low conflict/low WIR-I, high conflict/high WIR-I, and high conflict/low WIR-I. This classification provides a descriptive way to compare institutional performance under different levels of defensive-war selection pressure and identify regions whose resilience outcomes differ despite broadly similar levels of conflict exposure.

Third, a component heatmap decomposes the WIR-I into fiscal continuity, administrative functionality, digital capacity, entrepreneurial adaptation, and formal labor-market resilience. This allows comparison of the internal composition of regional resilience and helps identify whether similar overall WIR-I scores are associated with different combinations of functionality domains. A region may, for example, perform relatively strongly in digital or administrative functionality while remaining weaker in entrepreneurial or labor-market adaptation.

Taken together, these spatial and component-level analyses complement the regression models by showing where regional resilience is stronger or weaker and through which combinations of functionality domains these differences become observable. This is consistent with the multidimensional character of the WIR-I and avoids assuming that all oblasts follow a single pathway to wartime institutional resilience.

4.7 Regression Strategy

The regression analysis translates the hypotheses developed in Section 3.2 into a single reconciled empirical architecture based on the final WIR-I dataset. The strategy distinguishes between: (1) the baseline association between defensive-war selection pressure and the full WIR-I; and (2) associations between individual functionality domains and the remaining dimensions of WIR using reduced-index outcomes. Reduced-index specifications exclude the tested component from the dependent composite and therefore avoid mechanical part-whole correlation. Unless otherwise noted, continuous predictors are mean-centered, and clustered inference uses oblast-level clusters with small-sample t inference based on 23 cluster degrees of freedom.

4.7.1 Baseline Conflict-WIR Model (H1)

H1 is tested using a pooled oblast-quarter specification with year fixed effects. An oblast fixed-effects model is estimated as a robustness test to determine whether the pooled association also persists within oblasts over time:

$$WIR\text{-}I_{it} = \alpha + \beta_1 ConflictSeverity_{it} + \lambda_t + \varepsilon_{it}$$

where $WIR - I_{it}$ denotes the full 0-100 WIR-I for oblast i in period t; $ConflictSeverity_{it}$ represents the centered Conflict Severity Index; λ_t denotes year fixed effect; and ε_{it} is the error term. The coefficient β_1 captures the pooled conditional association between defensive-war selection pressure and WIR-I after accounting for common year and quarter effects. H1 predicts $\beta_1 < 0$. An oblast fixed-effects specification is used as the principal robustness test to distinguish between oblast-level and within-oblast variation.

4.7.2 Quarterly Functionality-Domain Models (H2-H5)

Because fiscal continuity, administrative functionality, digital capacity, and entrepreneurial adaptation are components of the WIR-I, H2-H5 are estimated using reduced dependent indices from which the tested domain has been removed. The common quarterly specification is:

$$WIR-I_{(-j),it} = \alpha + \beta_1 ConflictSeverity^{c}_{it} + \beta_2 x^{c}_{it} + \gamma_1 Frontline_i + \gamma_2 Capital_i + \lambda_y + \varepsilon_{it}$$

where $WIR - I_{(-j),it}$ is the 0–100 WIR-I recalculated for oblast i in quarter t after excluding functionality domain j, and x_{it}^{c} is the corresponding mean-centered functionality-domain predictor; and $ConflictSeverity_{it}^{c}$ is the mean-centered Conflict Severity Index. $Frontline_i$ and $Capital_i$ are binary controls for frontline status and capital-region status, respectively; γ_1 and γ_2 are denoting their associated coefficients; λ_y denotes year fixed effects; and ε_{it} is the error term. Separate models are estimated for fiscal continuity (H2), administrative functionality (H3), digital capacity (H4), and entrepreneurial adaptation (H5). Standard errors are clustered at the oblast level to account for dependence among repeated observations within oblasts. A positive β_2 is consistent with the corresponding hypothesis, indicating that stronger performance in the tested functionality domain is associated with stronger observed functionality across the remaining WIR-I domains, conditional on conflict severity, temporal effects, frontline status, and capital-region status.

Because the digital-capacity and entrepreneurial-adaptation measures do not contain fully independent quarterly variation over the entire study period, source-frequency sensitivity specifications are reported separately in Section 4.8.

4.7.3 Source-Faithful Labor-Market Model (H6)

Formal labor-market resilience requires a different temporal specification because registered-unemployment data are available as annual/reporting-period endpoints rather than as independently observed quarterly measures. H6 is therefore estimated at the oblast-year level using one source-faithful labor-market observation per oblast-year. The reduced WIR-I excluding the *Labor* component, together with conflict severity, is aggregated to the annual level, while the Labor sub-index retains the corresponding source observation. The specification is:

$$WIR\text{-}I(-Labor)_{,iy} = \alpha + \beta_1 ConflictSeverity_{iy}^{c} + \beta_2 LaborResilience_{iy}^{c} + \gamma_1 Frontline_i + \gamma_2 Capital_i + \lambda_y + \varepsilon_{iy}$$

where $WIR\text{-}I(-Labor)_{,iy}$ - the reduced WIR-I excluding the labor component for oblast i in year y, i indexes areas and y indexes years; $LaborResilience_{iy}^{c}$ is the centered formal labor-market resilience sub-index, based on reverse-standardized registered unemployment per 10,000 baseline residents; $ConflictSeverity_{iy}^{c}$ is centered annual conflict severity; $Frontline_i$ and $Capital_i$ are binary regional controls; γ_1 is the estimated coefficient on the frontline dummy; γ_2 is the estimated coefficient on the capital-region dummy; λ_y denotes year fixed effects; and ε_{iy} is the error term. Standard errors are clustered at the oblast level. A positive β_2 would be consistent with H6, indicating that stronger formal labor-market resilience is associated with stronger functionality across the remaining WIR-I domains. This source-faithful annual specification avoids treating repeated quarterly copies of a single unemployment endpoint as independent labor-market observations.

Taken together, the final regression strategy uses one reconciled H1-H6 record: H1 evaluates pooled conflict pressure; H2-H5 test direct functionality-domain associations using component-excluded outcomes; and H6 uses a source-faithful oblast-year specification. This architecture preserves the analytical distinction between external selection pressure, observed functionality domains, and the emergent WIR outcome while keeping the formal empirical test closely aligned with the first-generation measurement structure.

4.8 Robustness and Sensitivity Analysis

Robustness and sensitivity analyses are tailored to each hypothesis' measurement structure. For H1, an oblast fixed-effects model assesses whether the pooled conflict-WIR association persists after time-invariant regional heterogeneity is absorbed. H2 and H3 are likewise re-estimated with oblast fixed effects to distinguish pooled cross-regional associations from within-oblast relationships over time.

Because digital capacity is observed annually, H4 is re-estimated after aggregating the relevant outcome and conflict measures to the oblast-year level. Because entrepreneurial adaptation is represented by a regional 2022-2025 composite rather than a true quarterly series, H5 is tested using a 24-oblast cross-sectional specification with HC3 heteroskedasticity-robust standard errors.

For H6, the source-faithful oblast-year specification serves as the primary model rather than a robustness correction. A sensitivity analysis then excludes Donetsk, Luhansk, Kherson, and Zaporizhia, where occupation, displacement, and disrupted administrative reporting may make low registered-unemployment values especially difficult to interpret. Across the panel models, reported standard errors are clustered by oblast, and p-values use cluster-based t-inference for the 24-oblast panel. These checks help distinguish robust relationships from findings that are sensitive to regional heterogeneity, source frequency, or reporting constraints.

4.9 Supplementary Regional Innovation-System Analysis

The supplementary regional innovation indicators were obtained from official tables published by the State Statistics Service of Ukraine for the reporting periods 2018-2020, 2020-2022, and 2022-2024 (State Statistics Service of Ukraine 2025). These indicators are used descriptively and are not included in the WIR-I. The dataset reports the share of innovation-active enterprises by region and the proportion of such enterprises engaged in innovation cooperation, including with business partners, universities and higher-education institutions, public research institutes, public-sector customers, nonprofit organizations, innovation clusters, incubators, accelerators, technology-transfer centers, technological platforms, and partners in Ukraine and abroad. These indicators serve as contextual evidence of regional innovation-system capacities and relational structures from which wartime adaptive networks may evolve; they are not treated as direct measures of CMIE connectivity.

The supplementary analysis is descriptive rather than causal. The 2018-2020 innovation-activity share serves as a pre-full-scale-war reference point for historically accumulated regional innovation capacity, while changes observed in the 2020-2022 and 2022-2024 reporting windows are used to examine wartime reconfiguration of innovation activity and cooperation. The measures are kept analytically separate from the WIR-I and from H1-H6 because their multi-year reporting windows do not align with the quarterly WIR-I panel and because the innovation dataset has a different sampling structure.

Interpreting the supplementary statistics requires caution. The source notes that the 2020-2022 and 2022-2024 data exclude temporarily occupied territories and parts of territories where military actions are or were conducted, and that the dataset covers legal entities with 10 or more employees. Consequently, changes across reporting windows may reflect shifts in territorial and enterprise coverage as well as substantive innovation dynamics. The analysis therefore relies primarily on reported regional percentages, treats the data as non-annual, and uses the results only as complementary evidence on regional innovation activity, cooperation, and path-dependent adaptive potential.

4.10 Scope and Limitations

This study should be understood as a first-generation empirical operationalization of the WIRF. The WIR-I captures selected observable manifestations of wartime regional governance functionality through five empirically measurable domains: fiscal continuity, administrative functionality, digital capacity, entrepreneurial adaptation, and formal labor-market resilience. These domains provide a multidimensional empirical representation of how oblast-centered regional governance systems maintained and adapted selected functions under defensive-war pressure. They do not, however, exhaust the broader theoretical content of the WIRF.

Some theoretically important mechanisms and enabling conditions remain outside the present empirical operationalization. In particular, adaptive-governance processes, CMIE relational connectivity, civic mobilization and volunteer networks, governance integrity, defense-tech innovation, informal institutional adaptation, and international support cannot yet be measured consistently across oblasts and over the full analytical period. International military, financial, humanitarian, technical, and institutional support is particularly important because it shapes the resources and adaptive possibilities available to regional governance systems. Its absence from the first-generation WIR-I reflects limitations of consistent regional measurement rather than its theoretical exclusion from the WIRF. Future research may incorporate these factors as explanatory, conditioning, or moderating variables as sufficiently comparable oblast-level data become available.

Several data-related limitations should also be acknowledged. First, wartime data availability and reporting quality vary across indicators, regions, and years. Missing observations may reflect occupation, administrative disruption, reporting restrictions, or source limitations rather than the absence of institutional activity. Second, the empirical architecture combines genuinely quarterly indicators with annual or source-level contextual measures. The DTI is annual and repeated across quarters for panel compatibility; entrepreneurial adaptation is represented by a regional 2022-2025 composite; and registered unemployment is observed at annual/reporting-period endpoints. Source-consistent robustness or primary specifications are therefore used for these domains rather than interpreting repeated quarterly rows as independent temporal information. Third, registered unemployment captures formal, administratively recorded labor-market stress rather than total unemployment and is normalized using a stable 2022 baseline population denominator; it may be affected by displacement, migration, non-registration, occupation, and access to employment services. Fourth, the procurement layer is based on sampled procurement records rather than a complete census of Ukrainian public procurement and should therefore be interpreted as an observable signal of administrative and contracting continuity. Fifth, changes in the DTI methodology across years limit direct longitudinal comparison of raw scores; the analysis therefore relies primarily on within-year standardized measures of relative

regional digital capacity. Finally, the supplementary innovation statistics are reported for overlapping multi-year windows, have changing territorial coverage under occupation and hostilities, and cover legal entities with 10 or more employees. They are therefore used descriptively and are not incorporated into WIR-I or interpreted as a direct measure of CMIE formation.

The WIR-I should therefore be interpreted as a relative, sample-dependent measure of observed wartime regional governance functionality, rather than as an absolute or universal measure of institutional resilience. Its 0-100 transformation indicates the relative position of an oblast-period observation within the analytical sample; it does not represent a percentage of absolute resilience maximum or distance from a universal resilience threshold. Moreover, because the WIR-I captures selected observable outcomes of regional functionality rather than all mechanisms specified by the WIRF, its interpretation should remain tied to the empirical domains from which it is constructed.

Despite these limitations, the methodology provides a transparent, replicable first step toward empirically measuring WIR at the regional level. By distinguishing defensive-war selection pressure from institutional response, integrating multiple functionality domains within a common analytical structure, and testing component-excluded associations, the empirical strategy enables systematic comparison of how Ukrainian oblast-centered regional governance systems perform under spatially and temporally differentiated wartime pressure.

5. Results and Empirical Findings

5.1 Spatial Patterns of Wartime Institutional Resilience

This section presents the empirical results in four stages. First, the spatial distribution of WIR-I is examined across Ukrainian oblasts. Second, the relationship between defensive-war selection pressure and WIR is assessed descriptively. Third, the internal component structure of WIR-I is examined to identify heterogeneous regional functionality profiles. Fourth, panel regression models test the hypotheses concerning conflict severity and selected functionality domains. This section focuses on empirical patterns and statistical relationships; the Discussion develops their broader interpretation in relation to adaptive governance, CMIEs, and evolutionary institutional adaptation.

Fig. 2 shows the average WIR-I score by oblast for 2022-2025. This map shows substantial territorial variation in average WIR-I scores across Ukrainian oblasts. This pattern is consistent with the WIRF proposition that wartime institutional resilience is territorially differentiated rather than a uniform national condition.

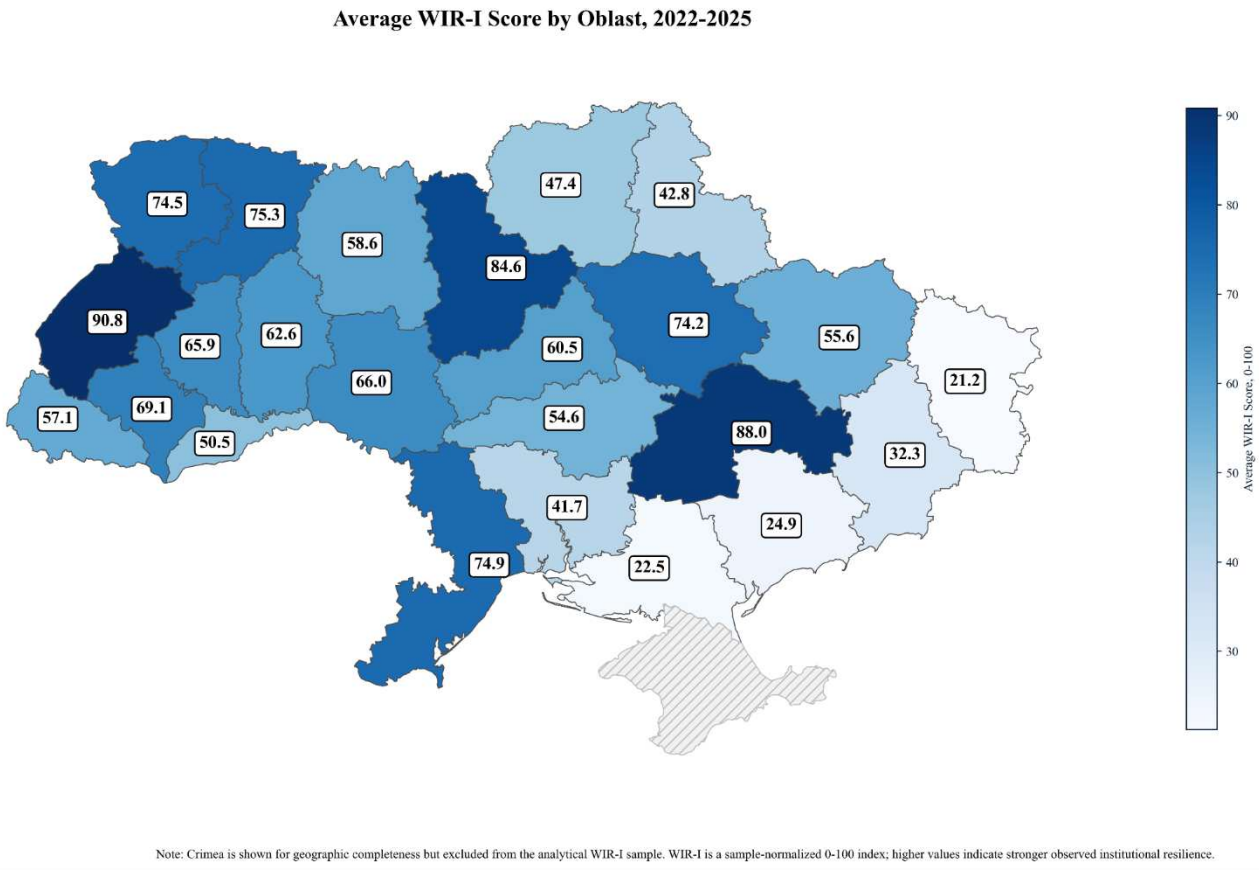


Fig. 2. Average Wartime Institutional Resilience Index (WIR-I) Score by Oblast, 2022–2025. Lower WIR-I values are shown in lighter shades; higher values in darker blue. *Note: Developed by the authors*

The highest average WIR-I scores are observed in several western, central, and major administrative-economic regions (oblasts), including Lviv, Dnipropetrovsk, Kyiv, Odesa, Volyn, Rivne, and Poltava oblasts. Their higher WIR-I scores are characterized by strengthened WIR where public administration, digital infrastructure, local finance, business activity, and socio-economic systems remain mutually reinforcing.

By contrast, the lowest average WIR-I scores are concentrated in heavily affected eastern and southern oblasts, including Luhansk, Kherson, Zaporizhzhia, Donetsk, and Mykolaiv. These regions experienced high levels of conflict exposure, occupation or partial occupation, infrastructure destruction, population displacement, disruption of public administration, and contraction of economic activity. Their lower WIR-I scores, therefore, reflect the cumulative impact of sustained wartime pressure on institutional, fiscal, administrative, and entrepreneurial functioning.

Kherson represents an important high-pressure case of institutional disruption, partial continuity, and adaptive reorganization under extreme wartime conditions. During the study period, the oblast experienced several successive phases of wartime disruption: occupation, deoccupation, destruction of administrative infrastructure, mass shelling after liberation, and the catastrophic consequences of the Kakhovka Dam's destruction. Under wartime conditions, regional authorities had to not only preserve existing governance routines but also rebuild public administration mechanisms amid extreme uncertainty. Kherson oblast represents a critical case of institutional adaptation and partial functionality under extreme wartime disruption.

At the same time, the map shows that conflict exposure does not automatically lead to institutional collapse. Dnipropetrovsk, Odesa, Kyiv, and Kharkiv oblasts maintain relatively high or moderate WIR-I scores despite significant wartime pressure. This pattern supports the WIRF argument that conflict severity functions as a form of selection pressure, but that regional adaptive capacity shapes how institutions respond to that pressure. In other words, wartime pressure tests resilience, but it does not fully determine it.

5.2 Conflict Severity and Wartime Institutional Resilience

Defensive-war selection pressure was highly uneven across Ukraine during 2022–2025. Conflict data show a persistent concentration of political violence in eastern, northeastern, and southern Ukraine, while missile, drone, and other long-range attacks extended wartime pressure well beyond the immediate frontline. This spatial pattern aligns with the WIRF conceptualization of defensive war as a continuous, evolving, and territorially differentiated selection environment.

The temporal composition of this pressure also shifted over the study period. The initial large-scale territorial shock of 2022 evolved into a prolonged environment marked by attrition, recurrent infrastructure attacks, technological escalation, and an increasingly extensive use of long-range strike systems. By 2025, missile and drone attacks imposed institutional and infrastructural pressures on regions well beyond active ground-combat zones (United Nations in Ukraine 2025). These developments reinforce the analytical importance of using a continuous Conflict Severity Index rather than a simple frontline/non-frontline classification.

Fig. 3 examines the descriptive relationship between average conflict severity and average WIR-I across oblasts for 2022-2025. The correlation between the two measures is approximately −0.58, indicating that areas exposed to higher average levels of conflict severity generally exhibit lower average observed wartime institutional resilience. This bivariate relationship is consistent with H1 and the WIRF proposition that intensified defensive-war selection pressure makes preserving regional governance functionality more difficult. The correlation should nevertheless be interpreted descriptively rather than causally; the multivariate regression analysis presented in Section 5.4 evaluates this relationship more formally and examines its robustness to alternative specifications.

The quadrant structure shown in Figure 3 provides additional insight into the territorial heterogeneity of WIR. The low-conflict/high-WIR-I quadrant includes oblasts such as Lviv, Rivne, Volyn, Ivano-Frankivsk, Ternopil, and Vinnytsia. These regions experienced comparatively lower direct military exposure while maintaining relatively strong observed governance functionality. Their wartime role also extended beyond their own territorial continuity, as many western and central oblasts became important locations for displaced populations, relocated enterprises, humanitarian logistics, administrative support, and other rear-area functions.

The high-conflict/low-WIR-I quadrant includes Donetsk, Kherson, Luhansk, Zaporizhzhia, Mykolaiv, Chernihiv, and Sumy oblasts. These regions experienced combinations of sustained military pressure, occupation or frontline proximity, infrastructure destruction, displacement, and disruption of administrative and economic activity. Their position in the lower-right quadrant illustrates the substantial constraints that prolonged and severe wartime pressure can impose on regional institutional functionality.

Particularly important for the WIRF are regions located in the high-conflict/high-WIR-I configuration. Dnipropetrovsk, Odesa, Kyiv, and Poltava oblasts combine relatively high conflict exposure with comparatively strong WIR-I performance, while Kharkiv exhibits high conflict severity alongside a more moderate WIR-I level. These observations show that conflict exposure alone does not fully explain regional resilience outcomes. Regions experiencing substantial wartime pressure may nevertheless preserve comparatively stronger functionality across selected fiscal, administrative, digital, entrepreneurial, and labor-market domains.

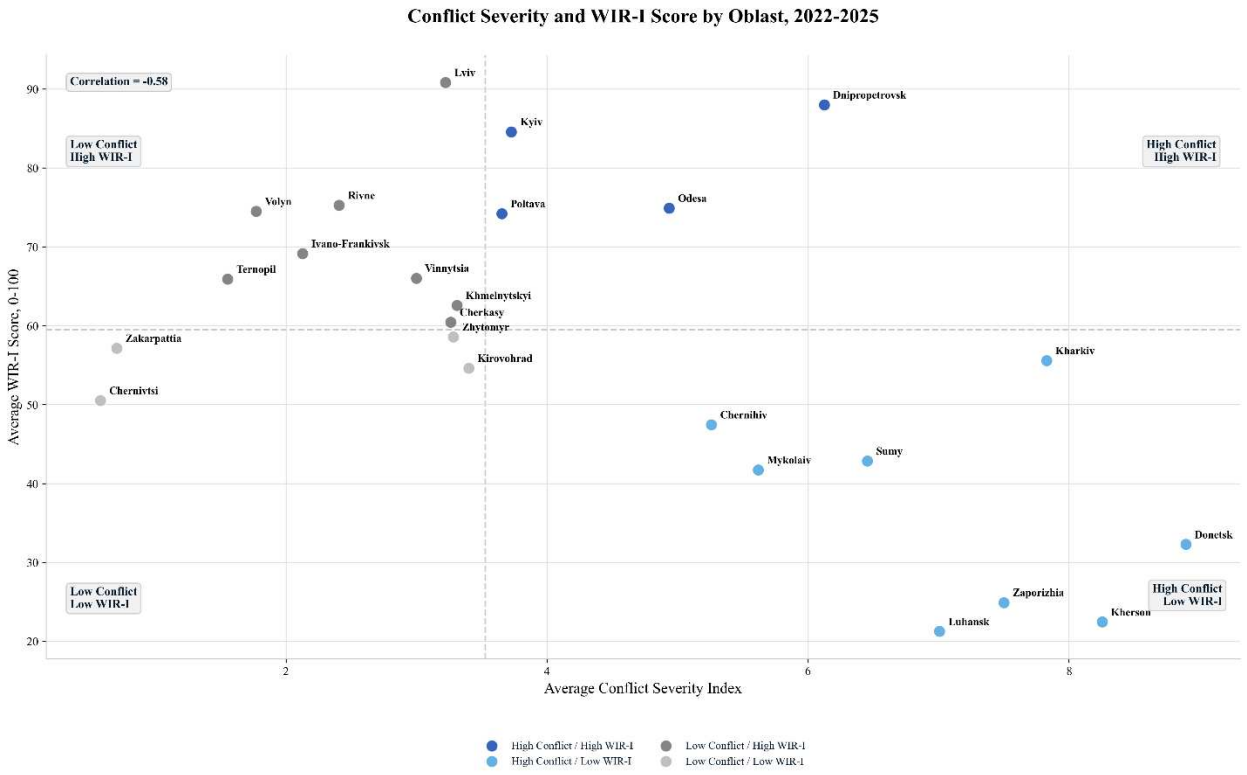


Fig. 3. Conflict Severity and WIR-I Score by Oblast, 2022–2025

Note: Developed by the authors

This heterogeneity is central to the WIRF. If regional WIR were determined primarily by the intensity of conflict exposure, oblasts subject to similar levels of defensive-war pressure would be expected to display broadly similar resilience outcomes. Instead, the substantial variation among highly exposed oblasts indicates that external selection pressure interacts with territorially differentiated institutional and adaptive capacities. The descriptive evidence therefore supports analytically separating conflict severity as external selection pressure from WIR as observed system-level functionality under that pressure.

At the same time, the negative bivariate relationship should not be overstated. The subsequent regression analysis shows that the negative association between conflict severity and WIR-I is statistically significant in the pooled baseline specification but is not robust to oblast fixed effects. This suggests that the observed relationship is driven primarily by persistent differences across oblasts rather than by a uniform within-oblast response to quarter-to-quarter changes in conflict severity. This pattern is consistent with the path-dependent logic of WIRF, which holds that regional wartime performance depends not only on changing external pressure but also on historically accumulated institutional, technological, fiscal, organizational, and relational capacities.

The next section therefore decomposes the WIR-I into its constituent functionality domains to examine how fiscal continuity, administrative functionality, digital capacity, entrepreneurial adaptation, and formal labor-market resilience contribute to heterogeneous regional resilience profiles.

5.3 Component Profiles of WIR-I

Fig. 4 decomposes the WIR-I into the five standardized functionality domains underlying the composite index: fiscal continuity, administrative functionality, digital capacity, entrepreneurial adaptation, and formal labor-market resilience. Unlike the 0-100 WIR-I presented in Fig. 2, the heatmap reports average standardized domain values. Positive values indicate above-average performance relative to the analytical sample, whereas negative values indicate below-average performance. Negative component values are therefore expected and do not contradict the positive 0–100 WIR-I scale.

Fig. 4 should be interpreted as a diagnostic representation of the internal composition of regional wartime resilience. Whereas Fig. 2 summarizes each oblast's overall relative WIR-I position, Fig. 4 shows the combination of functionality domains underlying that position. The heatmap demonstrates that similar overall WIR-I scores may arise from different configurations of fiscal, administrative, digital, entrepreneurial, and labor-market functionality, reinforcing the multidimensional character of WIR.

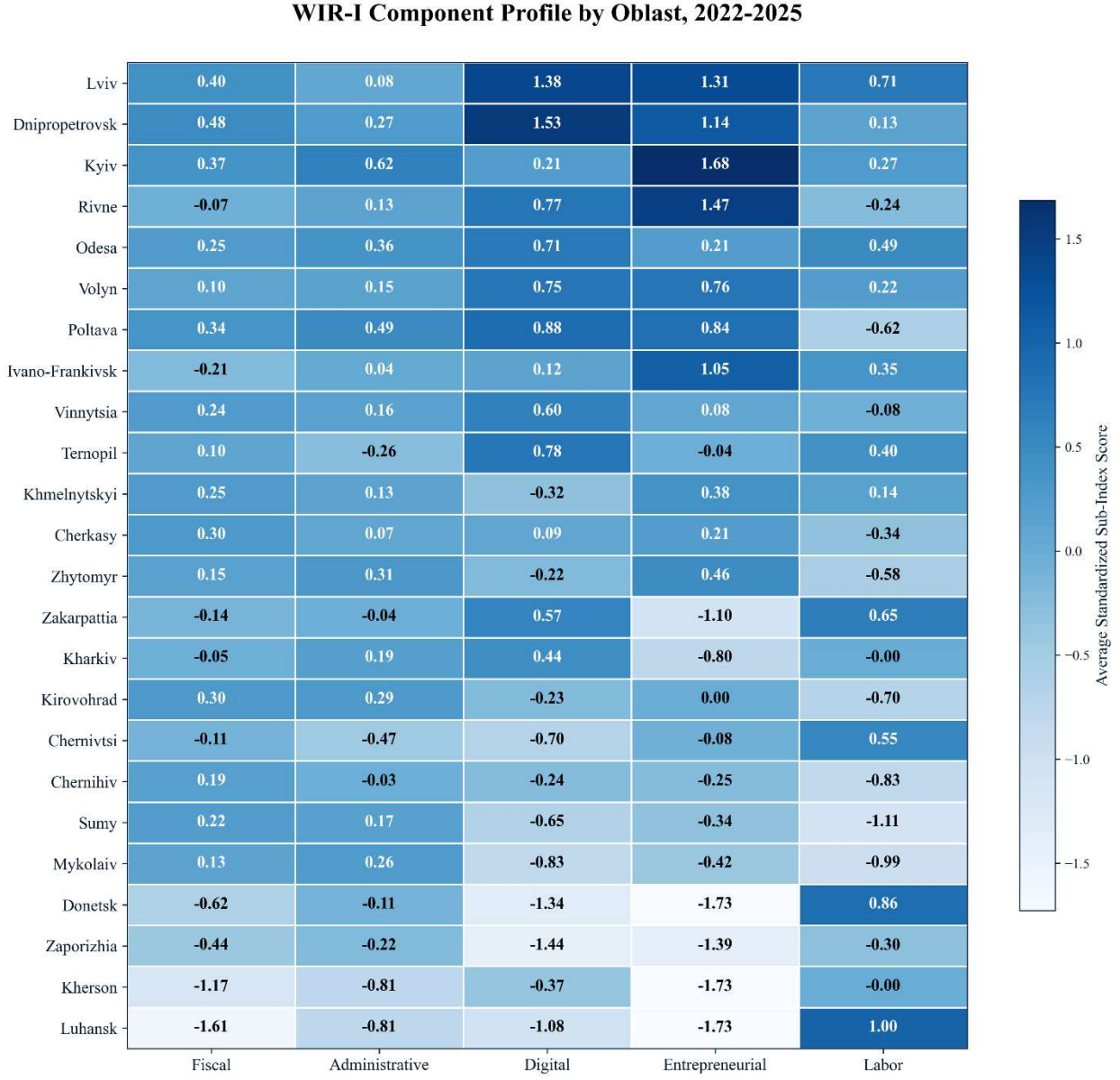


Fig. 4. Average Wartime Institutional Resilience Index (WIR-I) Component Profile by Oblast, 2022–2025

Note: Developed by the authors. Values represent average standardized domain scores. Positive values indicate above-sample-average performance and negative values indicate below-sample-average performance.

Several comparatively high-performing oblasts display strength across multiple functionality domains. Lviv, Dnipropetrovsk, Kyiv, Rivne, Odesa, Volyn, and Poltava oblasts exhibit relatively favorable profiles across more than one component. Lviv and Dnipropetrovsk, for example, show comparatively strong digital and entrepreneurial scores, while Kyiv displays particularly strong administrative and entrepreneurial components. These configurations suggest that higher overall WIR-I performance is not associated with a single uniform pathway but may reflect different combinations of complementary regional capacities.

Dnipropetrovsk oblast is particularly notable because it combines comparatively strong fiscal, administrative, digital, and entrepreneurial components despite substantial wartime exposure. Its profile illustrates an important feature of the WIRF: high external selection pressure can coexist with relatively strong observed functionality across several institutional domains. The heatmap itself does not establish the mechanisms producing this outcome, but it identifies Dnipropetrovsk as an important case of multidimensional functionality under substantial wartime pressure.

Kharkiv oblast exhibits a more heterogeneous profile. Its digital component is positive, and its administrative component is modestly positive, whereas entrepreneurial adaptation is substantially below the sample average. This pattern indicates that different dimensions of regional functionality did not respond uniformly to wartime disruption. In particular, the coexistence of comparatively stronger digital and administrative functionality with weaker entrepreneurial performance is consistent with the WIRF proposition that regional resilience may involve differentiated responses across governance and socioeconomic domains rather than uniform performance across all components.

The most conflict-exposed oblasts, including Luhansk, Kherson, Zaporizhzhia, and Donetsk, generally show weaker performance across several fiscal, administrative, digital, and entrepreneurial dimensions. These profiles are consistent with the substantial institutional constraints associated with prolonged occupation, frontline exposure, infrastructure disruption, displacement, and reduced administrative reach. However, interpret the component patterns as descriptive outcomes rather than direct estimates of the causal effects of these wartime pressures.

The formal labor-market component requires particular caution. Donetsk and Luhansk display relatively high values on this dimension despite weak performance across several other WIR-I domains. Because the labor indicator is based on registered unemployment rather than comprehensive labor-force data, low recorded unemployment may partly reflect displacement, reduced access to employment services, non-registration, occupation-related reporting constraints, or changes in the population remaining within the administrative reporting system. Accordingly, high formal labor-market resilience scores in heavily disrupted regions should not automatically be interpreted as evidence of stronger underlying labor-market conditions.

Overall, the component profiles demonstrate substantial within-region and cross-region heterogeneity in the composition of WIR. Regional resilience is associated with different combinations of fiscal continuity, administrative functionality, digital capacity, entrepreneurial adaptation, and formal labor-market resilience rather than with uniformly strong performance across all domains. The heatmap therefore complements the aggregate WIR-I by identifying the specific areas of relative strength and weakness underlying each oblast's overall position.

These descriptive patterns do not, however, establish whether individual functionality domains are systematically associated with stronger performance across the remaining WIR dimensions. The regression analysis in Section 5.4 therefore tests H1-H6 using the reduced-index strategy described in Section 4.7, distinguishing the association of conflict severity with WIR from the relationships between individual functionality domains and the remaining components of regional wartime resilience.

5.4 Regression Findings and Component-Level Interpretation

Table 2 presents the final reconciled H1-H6 regression record derived from the final no-Crimea WIR-I analytical panel. H1 retains the parsimonious pooled baseline conflict specification. H2-H5 use the controlled quarterly specification with year and quarter fixed effects, frontline and capital-region controls, and oblast-clustered standard errors. H6 is estimated at the source-faithful oblast-year level because the registered-unemployment source does not provide independent quarterly labor observations.

H1 receives support in the pooled baseline specification but is not supported in the oblast fixed-effects robustness model. Conflict severity is negatively and statistically significantly associated with the full WIR-I (β = -3.168, clustered SE = 0.925, p = .0023, N = 384, R^2 = .229). However, the association does not persist under oblast fixed effects (β = 0.209, p = .423). H1 is therefore interpreted as baseline-supported but robustness-sensitive, indicating that the negative conflict-WIR relationship is driven primarily by persistent differences between oblasts rather than by a stable within-oblast quarterly association.

H2 provides robust support for the fiscal-continuity hypothesis. Fiscal continuity is positively associated with the reduced WIR-I excluding the fiscal component (β = 8.949, clustered SE = 3.574, p = .0198, N = 384, R^2 = .516), and the relationship remains positive and statistically significant under oblast fixed effects (β = 4.688, p = .041). This indicates that stronger fiscal functionality is associated with stronger performance across the remaining WIR domains even after time-invariant oblast characteristics are absorbed.

Table 2. Final Hypothesis-Specific Regression Results

Hypothesis	Empirical test	β (clustered SE)	p; N; R^2	Final interpretation
H1	Conflict severity → full WIR-I	-3.168 (0.925)	.0023; 384; .229	Baseline support; robustness-sensitive
H2	Fiscal continuity → WIR-I excl. Fiscal	8.949 (3.574)	.0198; 384; .516	Supported
H3	Administrative functionality → WIR-I excl. Admin	3.075 (1.439)	.0434; 384; .543	Limited/conditional support
H4	Digital capacity → WIR-I excl. Digital	7.384 (1.619)	<.001; 384; .676	Supported
H5	Entrepreneurial adaptation → WIR-I excl. Entrepreneurial	9.379 (4.530)	.0498; 384; .468	Limited/conditional support
H6	Formal labor resilience → WIR-I excl. Labor	-1.667 (3.870)	.6707; 96; .568	Not supported

Notes: β denotes the hypothesis-relevant coefficient. Standard errors are clustered by oblast for panel and oblast-year specifications; cluster-based p-values use t-inference with 23 cluster degrees of freedom for the 24-oblast panel. H5 source-level robustness uses HC3 standard errors because it contains one observation per oblast. H1 includes year and quarter fixed effects. H2-H5 additionally control for conflict severity, frontline status, and capital-region status. H6 uses annual conflict severity, year fixed effects, frontline status, and capital-region status.

H3 receives more limited evidence. Administrative functionality is positively associated with the reduced WIR-I in the pooled controlled specification ($\beta = 3.075$, clustered SE = 1.439, $p = .0434$, $N = 384$, $R^2 = .543$), but the relationship becomes small and statistically insignificant under oblast fixed effects ($\beta = 0.347$, $p = .590$). Administrative functionality is therefore interpreted as conditionally associated with WIR rather than as a robust independent predictor, consistent with the possibility that procurement activity also reflects regional scale, emergency demand, reconstruction needs, defense-related requirements, and administrative concentration.

H4 is one of the strongest findings in the final empirical record. Digital capacity is positively and highly significantly associated with the reduced non-digital WIR-I ($\beta = 7.384$, clustered SE = 1.619, $p < .001$, $N = 384$, $R^2 = .676$). The result is virtually unchanged when the annual digital measure is analyzed at the source-consistent oblast-year frequency ($\beta = 7.397$, $p < .001$, $N = 96$). This robustness indicates that the digital result is not an artifact of assigning annual DTI observations across quarterly rows.

H5 provides positive but conditional evidence for entrepreneurial adaptation. In the pooled controlled model, entrepreneurial adaptation is positively associated with the reduced WIR-I excluding the entrepreneurial component ($\beta = 9.379$, clustered SE = 4.530, $p = .0498$, $N = 384$, $R^2 = .468$). However, the source-level 24-oblast cross-sectional robustness test remains positive but is not statistically significant ($\beta = 9.386$, $p = .149$). H5 is therefore interpreted as receiving limited or conditional support rather than unequivocal confirmation.

H6 is not supported by the available registered-unemployment measure. In the source-faithful oblast-year model, formal labor-market resilience is not significantly associated with the reduced WIR-I excluding the Labor component ($\beta = -1.667$, clustered SE = 3.870, $p = .6707$, $N = 96$, $R^2 = .568$). Excluding Donetsk, Luhansk, Kherson, and Zaporizhia changes the sign of the coefficient to positive, but the relationship remains statistically insignificant ($\beta = 4.927$, $p = .151$). The result reinforces the need to interpret registered unemployment as an administratively mediated indicator that is sensitive to displacement, occupation, registration access, and reporting continuity.

Taken together, the final regression record provides differentiated rather than uniform support for the six formal WIRF hypotheses. Fiscal continuity (H2) and digital capacity (H4) are the clearest supported relationships. Administrative functionality (H3) and entrepreneurial adaptation (H5) are positively associated with WIR in pooled models but are robustness-sensitive. Formal labor-market resilience as currently measured (H6) is not statistically supported. Conflict severity (H1) retains a strong negative pooled association with WIR-I, but the fixed-effects result indicates that this relationship primarily reflects between-oblast differences. The next section interprets these differentiated findings in relation to the mechanisms proposed by the WIRF.

5.5 Supplementary Evidence on Regional Innovation-System Capacity and Wartime Reconfiguration

Supplementary regional innovation statistics provide an additional descriptive window into the path-dependent innovation capacities that form part of the antecedent regional conditions identified by the WIRF. At the national level, the share of innovation-active enterprises increased from 10.5 percent in the 2020-2022 reporting

window to 17.6 percent in 2022-2024. The pattern is territorially heterogeneous. Kharkiv oblast increased from 9.5 percent to 26.0 percent over the same reporting windows; Dnipropetrovsk oblast increased from 12.6 percent to 20.4 percent; Lviv oblast from 12.4 percent to 19.1 percent; and Poltava from 9.1 percent to 19.0 percent. These shifts are consistent with substantial wartime reorganization of regional innovation activity, although they should not be interpreted as causal effects of war because territorial and enterprise coverage changed during the study period (State Statistics Service of Ukraine 2025).

The cooperation indicators provide a complementary relational perspective. Nationally, the share of innovation-active enterprises involved in innovation cooperation increased from 19.4 percent in 2020-2022 to 23.9 percent in 2022-2024. In Kharkiv oblast, the corresponding share increased from 17.3 percent to 26.5 percent. The dataset also shows that wartime innovation cooperation spans business-sector partners, universities, public research institutes, public-sector customers, nonprofit organizations, and innovation-support structures. This pattern is relevant to the WIRF because it illustrates the persistence and reconfiguration of heterogeneous innovation relationships under disruption.

These statistics provide supplementary evidence on the regional innovation system and collaborative capacities from which mission-oriented civil-military and transnational networks may evolve. The Kharkiv pattern is particularly informative in this respect: the oblast combines severe conflict exposure with a marked increase in measured innovation activity and innovation cooperation, reinforcing the interpretation of wartime adaptation as a process of path-dependent recombination rather than simple institutional preservation.

Kharkiv provides a particularly illustrative high-pressure example, combining severe conflict exposure with moderate WIR-I performance and a marked increase in measured innovation activity and cooperation; a fuller analysis of the city-level mechanisms lies beyond the scope of the present study.

To summarize, the empirical results identify distinct relationships among the functionality domains incorporated into the WIR-I, but these relationships should not be interpreted as direct measures of adaptive governance or the CMIE. Within the WIRF, adaptive governance is the cross-cutting coordination process that mobilizes and reconfigures distributed regional capabilities, while the CMIE provides the relational infrastructure that connects public, military, private, academic, civic, and transnational actors. The functionality domains measured in the WIR-I therefore represent observable outcomes through which these broader adaptive processes may become visible.

Appendix Fig. 6 provides supplementary descriptive evidence on the territorial distribution of innovative output and changes in innovation activity and cooperation between the pre-war and wartime reporting windows. These patterns illustrate the regional innovation-system capacities from which CMIE relationships may emerge and through which adaptive governance processes may support the functionality outcomes captured by the WIR-I.

6. Discussion

The findings raise a broader question that extends beyond the individual WIR-I domains: why do regions exposed to severe and prolonged wartime pressure follow different institutional trajectories? The WIRF suggests the answer may lie not only in the magnitude of the shock, but also in how historically accumulated regional capacities are recombined under pressure. This shifts attention from resilience as a stock of resources toward resilience as an evolutionary process of selection, recombination, and institutional retention. Future research should therefore examine not only whether regions possess particular capacities, but also how rapidly they can activate them, connect them across organizational boundaries, and convert temporary wartime responses into durable institutional routines.

The WIR-I already indicates that regional resilience is multidimensional, but future research could move beyond additive indices to identify distinct resilience configurations or pathways. Configurational approaches, latent-class analysis, clustering methods, or qualitative comparative analysis could help determine whether multiple combinations of capacities generate similar resilience outcomes. Such an approach would be especially valuable for explaining why apparently comparable regions can adapt through different institutional architectures.

A second research direction concerns the temporal dynamics of resilience. The present analysis necessarily summarizes institutional performance over quarterly and annual periods, but wartime adaptation is unlikely to be linear. Regions may experience an initial collapse, a period of improvisation, subsequent stabilization, and eventually institutional transformation. Some adaptations may produce immediate functionality but weaken longer-term capacity, whereas others may be costly at first but later generate stronger institutional performance. Future studies could therefore distinguish between resistance, recovery, adaptation, and transformation and examine whether different regional capacities matter at different stages of wartime disruption. Dynamic panel models, event-history approaches, change-point analysis, or sequence analysis could identify thresholds at which temporary coping becomes organizational learning or institutional reconfiguration.

A related question concerns institutional retention and hysteresis. Wartime adaptations may persist even after the pressures that generated them decline. Digital administrative routines, new procurement practices, civil–military partnerships, decentralized coordination mechanisms, and relationships between public institutions and civic or volunteer actors may become embedded in post-war governance, while other emergency arrangements may disappear once wartime incentives weaken. Future research could therefore examine which wartime adaptations are retained, reversed, or transformed and whether temporary responses become foundations for longer-term institutional change. Ukraine may provide a particularly valuable setting for studying these post-war institutional legacies.

Fiscal continuity also depends on whether the regional productive economy remains sufficiently functional to sustain the tax base. This opens a wider research question about the role of firm structure in regional wartime resilience. Regions dominated by a small number of large strategic enterprises may have substantial fiscal and logistical capacity but may also be vulnerable to targeted destruction or production disruption. Regions with more diversified SME and entrepreneurial structures may possess greater flexibility but less fiscal depth. Future research could investigate whether industrial concentration, firm-size structure, export orientation, supply-chain diversity, and relocation capacity generate different forms of resilience under sustained conflict.

The empirical prominence of digital capacity raises a broader theoretical issue. Digitalization appears to operate not merely as another discrete regional capability but potentially as a cross-cutting or general-purpose institutional technology. Digital systems can support service delivery, administrative coordination, fiscal management, procurement, communication, business activity, information exchange, and decentralized organization simultaneously. They may also shorten feedback cycles and facilitate the diffusion and retention of workable institutional responses. The strong association between digital capacity and broader wartime functionality is therefore consistent with the possibility that digital capability increases the usability of other regional capacities rather than functioning only as an isolated component of resilience.

Ukraine offers several examples of how such complementarities may operate. The Diia ecosystem supported continuity of administrative interaction and digital public services, while Diia.Business, Diia.Education, and Diia.City extended the digital environment into entrepreneurship, skills development, and the technology sector. DREAM created a unified environment for monitoring recovery and development projects (DREAM n.d.). In the civil-military innovation sphere, Brave1 provides an example of a platform connecting defense-technology actors with development, evaluation, and scaling processes. These examples show how digital capability may connect previously separate institutional functions and actor groups (Ministry of Digital Transformation of Ukraine n.d.-b).

Future WIRF research could therefore explicitly examine complementarity. Future models could test whether its contribution depends on other capacities. Digital systems may be particularly valuable when combined with effective public administration, functioning fiscal systems, entrepreneurial networks, or strong civic participation. Theoretically, this would shift the analysis from the independent contribution of individual capacities to the study of capacity interactions and institutional recombination, which better aligns with the WIRF's evolutionary logic.

Administrative functionality poses a different puzzle. Procurement offers a visible signal that public institutions retain the capacity to contract, allocate resources, and implement decisions, yet procurement activity is highly context-dependent. High procurement volumes may signal administrative capability, but they may also reflect reconstruction needs, humanitarian demand, military expenditure, institutional concentration, or simply the scale of regional public activity. This suggests that future WIR generation can better distinguish between administrative activity and administrative effectiveness. Measures of procurement completion, implementation speed, transparency, competitive intensity, delivery performance, audit outcomes, and institutional responsiveness may provide a richer picture than expenditure or tender activity alone.

The Ukrainian systems Prozorro and Dozorro demonstrate why this distinction matters. Digital procurement can preserve administrative continuity while also supporting transparency, monitoring, accountability, and oversight. Under wartime conditions, when emergency procurement and reconstruction increase both the urgency of spending and the risks associated with weaker controls, these institutional properties become particularly significant. Future research could therefore examine how procurement institutions adapt without sacrificing institutional integrity.

Entrepreneurial adaptation provides another area in which the current findings point toward a broader research agenda. Business formation and formal entrepreneurial activity represent only one visible expression of decentralized adaptation. Wartime entrepreneurship may involve firm relocation, changes in production, new supply relationships, technological experimentation, temporary organizational forms, and rapid entry into newly emerging markets. The available formal indicator captures only part of a much richer adaptive process.

The rapid development of Ukraine's defense-technology ecosystem is especially relevant in this regard. DefTech firms, startups, universities, technology platforms, military users, volunteer networks, and public institutions increasingly interact to develop and scale wartime technologies. These processes closely align with the evolutionary concepts of experimentation, variation, selection, and recombination. Yet conventional entrepreneurship measures

such as FOP registration cannot capture these relationships directly. Future WIRF research could therefore incorporate startup data, innovation-cooperation measures, patent or technology information, venture financing, procurement links, or network data to distinguish general entrepreneurial adaptation from mission-oriented innovation activity. This leads directly to one of the most important extensions of the WIRF: directly measuring the CMIE.

Direct measurement of the CMIE would make it possible to examine whether particular relational structures are associated with stronger adaptive performance. Future studies could use network analysis to investigate cross-sector connectivity, network density, brokerage, redundancy, centrality, and the role of bridging organizations linking military users, public authorities, firms, universities, civic organizations, and international partners. A particularly important question is whether effective wartime adaptation depends on centralized coordination, decentralized experimentation, or a hybrid structure in which locally generated innovations can be rapidly evaluated, selected, and scaled through wider institutional networks.

The labor-market result points to a broader methodological problem that deserves explicit attention: wartime adaptation often occurs outside conventional administrative statistics. Registered unemployment captures only a fraction of adjustment under displacement, mobilization, migration, remote work, informal employment, and occupational switching. The same measurement problem may affect other dimensions of wartime resilience. Informal volunteer networks, temporary civil–military collaborations, unregistered entrepreneurial activity, community-level mutual aid, and rapidly changing digital practices may be institutionally important precisely because they operate outside established reporting systems. Future generations of the WIR-I could therefore combine administrative statistics with mobility data, firm-level information, digital traces, network data, surveys, and qualitative evidence.

Another important extension concerns international support and regional absorptive capacity. External actors contribute humanitarian assistance, fiscal stabilization, technical expertise, reconstruction resources, defense-related support, and governance assistance, helping local institutions maintain operational continuity and develop context-specific responses under critical resource constraints. International support also enlarges the space for policy experimentation by mitigating scarcity and facilitating access to technological, financial, and organizational expertise. Its contribution to resilience may remain contingent. For external assistance to translate into durable institutional learning, coordinated implementation, and sustained resilience outcomes, functioning institutions, civic networks, digital infrastructures, transparent procurement systems, and adaptive governance mechanisms are necessary. Future research could examine why similar volumes of external support produce different institutional outcomes across regions and whether digital capacity, administrative quality, civic networks, procurement transparency, or prior international linkages condition the effective absorption of external resources. This would connect WIRF to the broader literature on absorptive capacity and institutional learning.

Governance quality and institutional integrity also deserve more explicit treatment in future generations of the framework. Transparent and accountable institutions may facilitate resource allocation, coordination, trust, and the retention of successful adaptive routines. Conversely, corruption and rent-seeking may distort information, redirect resources, weaken public trust, and impede the institutionalization of effective responses. Within the WIRF, these factors are best understood not as additional forms of external wartime pressure, but as endogenous institutional conditions that shape the capacity to adapt under external pressure. Future WIR-I versions could therefore incorporate appropriately validated measures of institutional quality where reliable subnational data become available.

Taken together, these considerations suggest a natural progression for the WIRF. The present study provides a first-generation empirical operationalization focused on observable wartime functionality. The next generation should move from asking primarily which regional capacities are associated with wartime functionality toward examining how capacities interact, how actors become connected through CMIE networks, how responses are selected and scaled, and which wartime adaptations become institutionally retained over time. In this sense, WIR should increasingly be treated as an evolving system-level outcome of historically accumulated capacities, adaptive governance, relational coordination, and institutional learning under prolonged defensive-war selection pressure. This interpretation aligns with the WIRF's central proposition that WIR emerges when distributed regional capacities are mobilized and recombined through adaptive governance operating across civil-military relational networks.

7. Conclusion

This study develops the Wartime Institutional Resilience Framework (WIRF) and provides a first-generation empirical operationalization of Wartime Institutional Resilience across 24 Ukrainian oblasts during 2022-2025. Its central conclusion is that WIR is neither a uniform national characteristic nor a simple function of conflict intensity.

WIR is a territorially differentiated and evolving system-level outcome that reflects how regional governance systems preserve and reconfigure essential functionality under prolonged defensive-war pressure.

The Ukrainian evidence reveals substantial regional heterogeneity in WIR. These differences reflect both the spatially uneven character of defensive war and the historically accumulated institutional, economic, technological, human, and relational capacities regions brought to the shock. Greater conflict severity is associated with lower regional functionality in pooled comparisons, but it does not determine a single institutional trajectory. Regions exposed to comparable levels of wartime pressure may perform differently because they differ in their organizational structures, resource bases, actor networks, innovation capacities, and opportunities for coordination and recombination. The findings therefore support a path-dependent interpretation of wartime resilience in which the consequences of external pressure depend partly on the capacities and institutional relationships accumulated before the shock and subsequently mobilized under it.

This distinction is also central to the paper's empirical contribution. By keeping conflict severity analytically separate from the WIR-I, the framework distinguishes the intensity of the selection environment from the institutional performance observed within that environment. A heavily attacked region should not automatically be classified as institutionally non-resilient simply because it experiences greater destruction or exposure. The relevant question is how effectively the regional governance system preserves and reorganizes essential functionality under the conditions it actually confronts. The first-generation WIR-I provides a comparative empirical basis for addressing this question across territorially differentiated wartime environments.

Among the observed functionality domains, fiscal continuity and digital capacity show the clearest and most robust relationships with broader wartime functionality. Together, these findings point to two complementary foundations of contemporary institutional resilience: the preservation of a viable resource base and the capacity to coordinate activity across organizational and territorial boundaries. Fiscal continuity sustains the material basis of public action, while digital capacity supports information flows, service delivery, procurement, communication, coordination, and organizational flexibility when conventional physical channels are disrupted.

The significance of digitalization extends beyond preserving existing administrative services. Ukraine's wartime experience suggests that digital capacity can support a more decentralized, networked, and innovation-oriented model of institutional adaptation. Digital platforms allow public authorities, businesses, communities, universities, civic actors, and military and technology networks to interact across organizational boundaries, shorten feedback cycles, and facilitate the communication, adaptation, and scaling of localized responses. From this perspective, digitalization may function not simply as a separate capability but as an enabling infrastructure through which other distributed regional capacities become more readily connected and recombined.

Entrepreneurial adaptation points to a related transformation in regional economic organization. Wartime adjustment extends beyond the survival of existing firms to changes in organizational scale, business models, employment arrangements, and forms of economic participation. The growing role of microenterprises, small specialized teams, project-based activity, flexible work arrangements, business relocation, and rapid responses to emerging demand suggests a movement toward more decentralized, agile, and networked forms of economic activity. These developments raise an important agenda for further research into whether prolonged wartime disruption produces enduring changes in regional business structures and whether such organizational flexibility contributes to longer-term regional adaptive capacity.

The labor-market findings reveal a parallel transformation that conventional administrative indicators capture only partially. Registered unemployment cannot capture the full range of adjustment occurring through displacement, migration, mobilization, occupational change, remote work, informal activity, project-based employment, sectoral reallocation, and changing labor-force participation. Future generations of WIR research should therefore examine labor-market resilience less as employment stability alone and more as the capacity of regional labor systems to reorganize human capital under sustained disruption.

A further implication concerns the relationship among defensive war, science, technology, and innovation. Prolonged existential pressure compresses decision-making horizons and creates exceptional demand for rapid problem-solving, experimentation, and technological adaptation. Under such conditions, scientific, engineering, entrepreneurial, military, and civic knowledge that previously developed within relatively separate institutional domains may become more closely connected and increasingly mission-oriented. Ukraine's emerging DefTech ecosystem, digital-governance platforms, rapid technological experimentation, and expanding cooperation among firms, universities, military users, public institutions, and volunteer networks illustrate this process. Defensive-war selection pressure can shorten innovation cycles, intensify operational feedback, and accelerate the recombination, testing, diffusion, and scaling of scientific and technological solutions. This does not imply that war itself generates innovation; rather, existential pressure can fundamentally alter how existing knowledge and capabilities are connected, selected, and translated into practical responses.

The supplementary regional innovation evidence points in the same direction by revealing territorially differentiated patterns of innovation activity and cooperation. These patterns raise an important next question for the WIRF: whether and how pre-existing Regional Innovation Systems are reconfigured under defensive-war pressure into more mission-oriented, civil–military, and transnational networks. Direct analysis of these relationships could trace how firms, universities, military actors, public institutions, civic organizations, technology platforms, and international partners become connected and how particular network structures influence the generation, evaluation, scaling, and institutional retention of wartime innovations.

This question brings the analysis back to the CMIE. Within the WIRF, the CMIE provides the evolving relational infrastructure that connects heterogeneous actors and distributed capabilities, while adaptive governance describes the processes by which these capabilities are mobilized, coordinated, recombined, tested, selected, scaled, and retained. The broader theoretical contribution of the WIRF is therefore to shift resilience analysis from the possession of resources to the evolutionary processes through which distributed capacities are transformed into coordinated adaptive performance. What matters is not only what a region possesses when disruption begins, but also whether those capacities can be activated, connected, recombined, and institutionalized as conditions change.

The post-war period will provide an especially important test of this evolutionary argument. Some wartime responses may disappear once emergency pressures decline, while others - digital administrative routines, procurement innovations, civil–military partnerships, decentralized coordination mechanisms, flexible organizational forms, and new relationships among public institutions, firms, universities, and civic actors - may become embedded in longer-term governance structures. Examining which adaptations are retained, reversed, or transformed will make it possible to determine whether temporary wartime responses become foundations for new institutional and regional development trajectories.

Ukraine therefore provides more than a case of institutional endurance under extreme disruption. It demonstrates how prolonged defensive war can produce divergent regional trajectories of continuity, adaptation, and transformation, shaped by the interaction of uneven external pressure with historically accumulated regional capacities and relationships. The broader relevance of the WIRF lies in providing an analytical framework for understanding how those capacities are tested, how heterogeneous actors become connected, how workable responses are selected and scaled, and how successful adaptations may reshape the institutional possibilities available in the future.

The central implication of this study is therefore not that war produces resilience, nor that any single capacity protects regions from disruption. Rather, WIR emerges through the capacity of regional governance systems to mobilize, connect, recombine, and institutionally retain distributed capabilities through adaptive governance operating across civil–military relational networks under prolonged defensive-war selection pressure.

These implications are particularly relevant for regional and local authorities, central-government bodies responsible for territorial and recovery policy, international donors and development institutions, and organizations participating in civil–military and regional innovation ecosystems. For public authorities, the framework can support the identification of functional bottlenecks and differentiated intervention priorities. For international partners, it offers a basis for distinguishing resource scarcity from institutional absorptive-capacity constraints. For business, academic, civic, and innovation actors, the CMIE perspective highlights the importance of cross-sector connectivity, rapid feedback, experimentation, and the scaling of locally generated solutions.

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References

1. ACLED. (n.d.). *Ukraine Conflict Monitor*. Armed Conflict Location & Event Data Project. Retrieved June 2, 2026, from https://acleddata.com/monitor/ukraine-conflict-monitor
2. Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R., & Rockström, J. (2005). Social-ecological resilience to coastal disasters. *Science, 309*(5737), 1036-1039. https://doi.org/10.1126/science.1112122
3. Béné, C. (2013). Towards a quantifiable measure of resilience (IDS Working Paper 434) (27 pp.). Brighton: Institute of Development Studies.

4. Béné, C., Wood, R., Newsham, A., & Davies, M. (2012). *Resilience: New utopia or new tyranny? Reflection about the potentials and limits of the concept of resilience in relation to vulnerability reduction programmes* (IDS Working Paper No. 405). Institute of Development Studies. https://doi.org/10.1111/j.2040-0209.2012.00405.x
5. Béné, C., & Doyen, L. (2018). *From resistance to transformation: A generic metric of resilience through viability*. *Earth's Future,* 6(7), 979–996. https://doi.org/10.1002/2017EF000660
6. Béné, C., Newsham, A., Davies, M., Ulrichs, M., & Godfrey-Wood, R. (2014). Resilience, poverty and development. *Journal of International Development, 26*(5), 598–623. https://doi.org/10.1002/jid.2992
7. Boschma, R., & Martin, R. (2007). Constructing an evolutionary economic geography. *Journal of Economic Geography, 7*(5), 537–548. https://doi.org/10.1093/jeg/lbm021
8. Boschma, R. (2015). Towards an evolutionary perspective on regional resilience. *Regional Studies*, 49(5), 733-751. https://doi.org/10.1080/00343404.2014.959481
9. Bouchard, G. (2013). Neoliberalism in Québec: The response of a small nation under pressure. In P. A. Hall & M. Lamont (Eds.), Social resilience in the neoliberal era (pp. 267–292). Cambridge University Press. https://doi.org/10.1017/CBO9781139542425.016
10. Bourbeau, P. (2013). Resilience and international politics: Premises, debates, agenda. *International Studies Review, 15*(3), 367–380.
11. Brovko, O. (2024). Local government resilience in the face of Russian aggression: the case of Ukraine. *Territory, Politics, Governance*. https://doi.org/10.1080/21622671.2024.2327369
12. Cantner, U. (2016). Foundations of economic change: An extended Schumpeterian approach. *Journal of Evolutionary Economics, 26*(4), 701–736. https://doi.org/10.1007/s00191-016-0479-z
13. Capello, R. (2015). *Regional economics* (2nd ed.). Routledge.
14. Carpenter, S. R., Walker, B., Anderies, J. M., & Abel, N. (2001). From metaphor to measurement: Resilience of what to what? *Ecosystems, 4*(8), 765–781. https://doi.org/10.1007/s10021-001-0045-9
15. Clausewitz, C. von. (1976). *On war* (M. Howard & P. Paret, Eds.). Princeton University Press. (Original work published 1832)
16. Cooke P., Uranga M. G., Etxebarria G. (1998). Regional Systems of Innovation: An Evolutionary Perspective. *Environment and Planning*. Vol. 30(9). 1563-1584. https://doi.org/10.1068/a301563
17. Cooke, P. (2013). Reframing Regional Development: Complex Systems Integration, 'Emergence', and Policy Modularisation. In P. Cooke (Ed.), *Re-framing regional development: Evolution, innovation and transition* (pp. 1–26). Routledge.
18. Cutter, S., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. *Global Environmental Change*, 18(4), 598–606. https://doi.org/10.1016/j.gloenvcha.2008.07.013
19. Davoudi, S. (2012). Resilience: A bridging concept or a dead end? *Planning Theory & Practice,* 13(2), 299–333.
20. Dopfer, K., & Potts, J. (2008). *The general theory of economic evolution*. Routledge.
21. DREAM. (n.d.). *Digital Restoration Ecosystem for Accountable Management*. https://dream.gov.ua/en
22. European Business Association. (2026, April 15). *Digital Transformation Index of Regions -2025*. https://eba.com.ua/en/indeks-tsyfrovoyi-transformatsiyi-regioniv-2025/
23. Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change, 16*(3), 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002
24. Gall, M. (2013). From representation to actionability: Lessons from disaster loss and damage databases. In T. Mitchell (Ed.), *Defining disaster resilience: Implications for the post-2015 development agenda*. Overseas Development Institute / OECD.
25. Granovetter, M. (1985). Economic action and social structure: The problem of embeddedness. *American Journal of Sociology, 91*(3), 481–510. https://doi.org/10.1086/228311
26. Gustafsson M., Matveieva O., Wihlborg E., Borodin Ye., Mamatova T., Kvitka S. (2025) Adaptive governance amidst the war: Overcoming challenges and strengthening collaborative digital service provision in Ukraine. Government Information Quarterly, 42(3). 102056. https://doi.org/10.1016/j.giq.2025.102056
27. Hannah, D. P., & Eisenhardt, K. M. (2018). How firms navigate cooperation and competition in nascent ecosystems. *Strategic Management Journal,* 39(12), 3163–3192. https://doi.org/10.1002/smj.2750

28. Hassink, R., & Klaerding, C. (2011). Evolutionary approaches to local and regional development policy. In A. Pike, A. Rodríguez-Pose, & J. Tomaney (Eds.), *Handbook of local and regional development* (pp. 139-148). Routledge.
29. Hodgson, G.M. (1988). *Economics and Institutions: A Manifesto for a Modern Institutional Economics*. Polity Press.
30. Hodgson, G.M. (1997). The ubiquity of habits and rules. *Cambridge Journal of Economics*, 21(6), 663-684.
31. Hodgson, G.M. (2004). *The Evolution of Institutional Economics: Agency, Structure and Darwinism in American Institutionalism*. Routledge.
32. Hodgson, G.M. (2006). What are institutions? *Journal of Economic Issues*, 40(1), 1-25.
33. Holling CS (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics,* 4(1), 1-23. https://doi.org/10.1146/annurev.es.04.110173.000245
34. Klein, R. J. T., Nicholls, R. J., & Thomalla, F. (2003). Resilience to natural hazards: How useful is this concept? *Environmental Hazards, 5*(1–2), 35–45. https://doi.org/10.1016/j.hazards.2004.02.001
35. Kutsenko, O. (2025). Resilience under fire: navigating societal challenges, agency, and innovation in times of war. *Innovation: The European Journal of Social Science Research,* 38. 1-10. https://doi.org/10.1080/13511610.2025.2465177
36. Lipparini, A., & Sobrero, M. (1994). The glue and the pieces: Entrepreneurship and innovation in small-firm networks. *Journal of Business Venturing, 9*(2), 125–140. https://doi.org/10.1016/0883-9026(94)90005-1
37. Lundvall, B. Å. (2016). Innovation as an interactive process: From user-producer interaction to the national system of innovation. In B. Å. Lundvall (Ed.), *The learning economy and the economics of hope* (pp. 3–69). Anthem Press.
38. Malešević, S. (2010). *The sociology of war and violence*. Cambridge University Press.
39. Martin, R., Sunley, P., Gardiner, B., & Tyler, P. (2016). How regions react to recessions: Resilience and the role of economic structure. *Regional Studies, 50*(4), 561–585. https://doi.org/10.1080/00343404.2015.1136410
40. Martinelli, F., Moulaert, F., & Novy, A. (Eds.). (2013). *Urban and regional development trajectories in contemporary capitalism*. Routledge.
41. Mazzucato, M. (2018). Mission-oriented innovation policy: Challenges and opportunities. *Industrial and Corporate Change, 27*(5), 803–815.
42. Melnykovska, I. & Wilson Sokhey S. (2025). The local and regional dimension of Ukraine's resilience during Russia's full-scale invasion: an introduction. *PostSoviet Affairs*, 41:5, 401-410. https://doi.org/10.1080/1060586X.2025.2545626
43. Metcalfe, J.S. (1994). Evolutionary economics and technology policy. *Economic Journal*, 104(425), 931-944.
44. Metcalfe, J.S. (1997). Evolutionary economics and creative destruction. *Journal of Evolutionary Economics*, 7, 3-23.
45. Metcalfe, J.S. (1998). *Evolutionary Economics and Creative Destruction*. Routledge.
46. Ministry of Digital Transformation of Ukraine. (n.d.-a). *Diia. Digital Community: National web portal for digital leaders*. Retrieved June 1, 2026, from https://hromada.gov.ua/
47. Mitchell, T. (Ed.). (2013). *Defining disaster resilience: Implications for the post-2015 development agenda*. Overseas Development Institute / OECD Scoping Study.
48. Ministry of Digital Transformation of Ukraine. (2025, May 13). *Digitalization of regions and communities: First measurements of 2025*. https://thedigital.gov.ua/news/technologies/tsifrovizatsiya-regioniv-i-gromad-pershi-vimiryuvannya-2025-roku.
49. Ministry of Digital Transformation of Ukraine. (n.d.-b). *Projects*. https://thedigital.gov.ua/projects
50. Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., & Giovannini, E. (2008). Handbook on constructing composite indicators: Methodology and user guide. OECD Publishing / Joint Research Centre of the European Commission. https://doi.org/10.1787/9789264043466-en
51. Nelson, R. R., & Winter, S. G. (1982). *An evolutionary theory of economic change*. Belknap Press/Harvard University Press.
52. Nelson, R. R. (2005). *Technology, Institutions, and Economic Growth.* Harvard University Press.
53. Nelson, R. R. (1996). The sources of economic growth. Harvard University Press.

54. Nelson, D. R., Adger, W. N., & Brown, K. (2007). Adaptation to environmental change: Contributions of a resilience framework. *Annual Review of Environment and Resources,* 32, 395–419. https://doi.org/10.1146/annurev.energy.32.051807.090348
55. OECD. (2024). *Enhancing Resilience by Boosting Digital Business Transformation in Ukraine*. OECD Publishing. https://doi.org/10.1787/4b13b0bb-en
56. Olsson, P., Gunderson, L. H., Carpenter, S. R., Ryan, P., Lebel, L., Folke, C., & Holling, C. S. (2006). Shooting the Rapids: Navigating Transitions to Adaptive Governance of Social-Ecological Systems. *Ecology and Society*, 11(1), 18. https://doi.org/10.5751/ES-01595-110118
57. Pimm, S. (1984). The complexity and stability of ecosystems. *Nature*, 307, 321–326. https://doi.org/10.1038/307321a0
58. Putnam, R. D. (2000). *Bowling alone: The collapse and revival of American community*. Simon & Schuster.
59. Reznikova, O., & Korniievskyi, O. (2024). Resilience of the Ukrainian society in wartime: Components and influencing factors. *Eastern Journal of European Studies, 15*(1), 113–133. https://doi.org/10.47743/ejes-2024-0105
60. Schumpeter, J. A. (1947). The creative response in economic history. *Journal of Economic History,* 7(2), 149–159.
61. Simmie, J., & Martin, R. (2010). The economic resilience of regions: Towards an evolutionary approach. Cambridge Journal of Regions, Economy and Society, 3(1), 27–43. https://doi.org/10.1093/cjres/rsp029
62. State Statistics Service of Ukraine. (2025). *Regional indicators of innovation activity and innovation cooperation among enterprises, 2018–2020, 2020–2022, and 2022–2024* [Data set]. https://ukrstat.gov.ua/operativ/menu/menu_u/ni.htm
63. Tilly, C. (1990). *Coercion, capital, and European states, AD 990–1990*. Wiley-Blackwell.
64. Tura T., Harmaakorpi V. (2005) Social Capital in Building Regional Innovative Capability. *Regional Studies.* 39(8). 1111-1125. DOI: https://doi.org/10.1080/00343400500328255
65. United Nations in Ukraine. (2025, November 25). *Civilian casualties mount as Russian armed forces step up attacks on Ukraine's energy infrastructure ahead of winter, UN human rights monitors say*. https://ukraine.un.org/en/305972-civilian-casualties-mount-russian-armed-forces-step-attacks-ukraine%E2%80%99s-energy-infrastructure
66. Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society*, 9(2), 5.
67. Walzer, M. (1977). *Just and unjust wars*. Basic Books.
68. Webber, D. J., Healy, A., & Bristow, G. (2018). Regional growth paths and resilience: A European analysis. *Economic Geography, 94*(4), 355–375. https://doi.org/10.1080/00130095.2017.1419057
69. Winderl, T. (2014). *Disaster resilience measurements: Stocktaking of ongoing efforts in developing systems for measuring resilience*. United Nations Development Programme, Bureau for Crisis Prevention and Recovery.

Appendix A. Construction and Distribution of the Conflict Severity Index

A.1. Construction of the Conflict Severity Index

The Conflict Severity Index (CSI) summarizes three complementary dimensions of regional wartime exposure in a continuous measure of defensive-war selection pressure: conflict-event frequency, recorded fatalities, and conflict exposure. The three constituent indicators are the number of recorded conflict events ($conf_events$), the number of recorded fatalities ($conf_fatalities$), and the conflict-exposure measure ($conf_exposure$) for oblast (i) in quarter (t). These indicators capture, respectively, the frequency of conflict activity, its direct human cost, and the broader spatial and population burden associated with recorded conflict activity.

Because the raw conflict measures are highly right-skewed, with a relatively small number of oblast-quarter observations experiencing exceptionally high levels of conflict activity, fatalities, or exposure, each indicator is transformed using the natural logarithm of one plus its observed value: $ln(1 + x)$. Adding one preserves genuine zero observations because $ln(1) = 0$, while the logarithmic transformation reduces the disproportionate influence of extreme values.

The transformed indicators are combined using the following fixed weighted composite:

$$CSI_{it}=0.40ln(1+conf_events_{it})+0.40ln(1+conf_fatalities_{it})+0.20ln(1+conf_exposure_{it}).$$

The coefficients represent theory-informed construction weights rather than statistically estimated parameters. Conflict-event frequency and fatalities receive greater weights because they capture the most direct manifestations of realized wartime intensity through event incidence and human lethality. The exposure component receives a smaller weight because it represents a broader contextual dimension of spatial and population burden. The lower coefficient also limits the influence of the exposure measure, whose logged values remain comparatively large. The resulting specification therefore combines conflict frequency, lethality, and broader wartime reach while preventing the exposure component from disproportionately determining the composite index.

Higher CSI values identify oblast-quarter observations experiencing a more severe combination of conflict frequency, fatalities, and exposure. The index measures the intensity of external wartime selection pressure rather than regional institutional performance. It is therefore treated as an explanatory variable and is not included in the Wartime Institutional Resilience Index (WIR-I).

The underlying conflict data are organized as a balanced oblast-quarter panel covering 24 oblasts from 2022Q1 through 2025Q4. Within this analytical period, oblast-quarter observations with no recorded ACLED conflict activity are retained as genuine zero observations rather than treated as missing.

For the regression analysis, the CSI is subsequently mean-centered: ($conflict_c$). Mean-centering facilitates the interpretation of the regression coefficients and interaction terms but does not alter the construction, ordering, or substantive meaning of the index.

A.2. Spatial Distribution and Event Dynamics

Fig. 5 complements the methodological description by presenting the spatial distribution of the calculated Conflict Severity Index alongside the temporal composition of political violence events recorded by ACLED. Fig. 5. reports the mean CSI for each Ukrainian oblast over the analytical period.

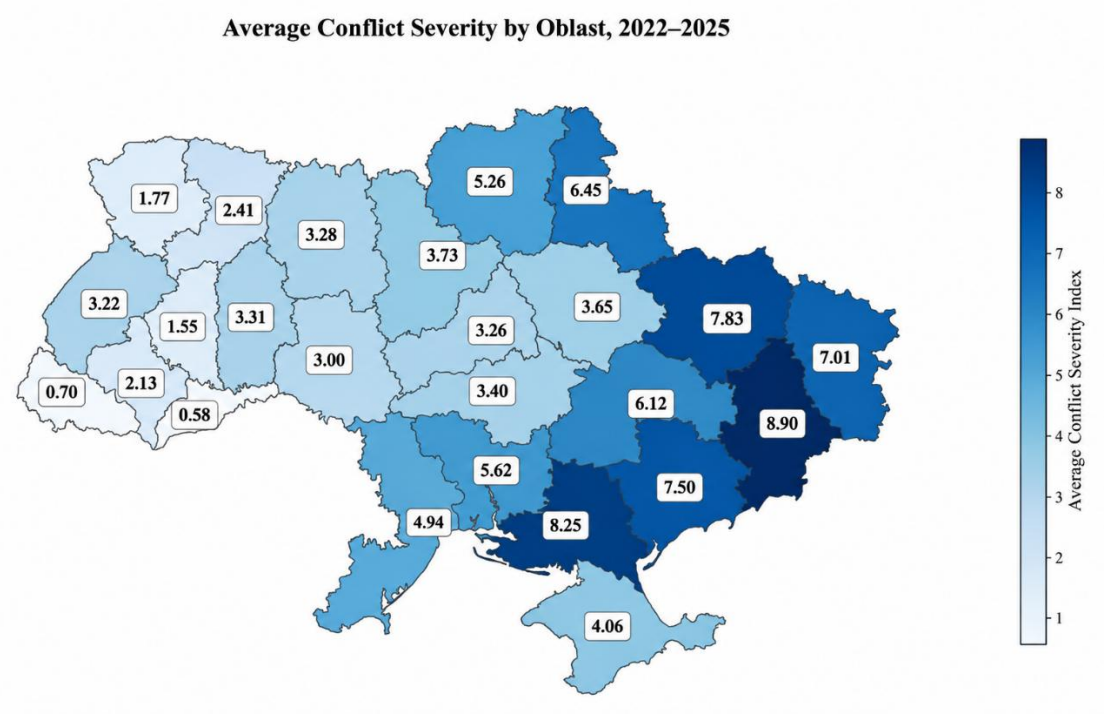


Fig. 5. Fig. 5. Average Conflict Severity Index across Ukrainian oblasts, 2022Q1–2025Q4.

Notes: *Values represent the mean Conflict Severity Index for each oblast over 2022Q1–2025Q4. Higher values indicate greater conflict severity. Crimea is displayed but excluded from the 24-oblast analytical sample.* ***Source:*** *Authors' calculations based on ACLED event-level data.*

Appendix B. Regional Innovation-System Capacity and Wartime Reconfiguration

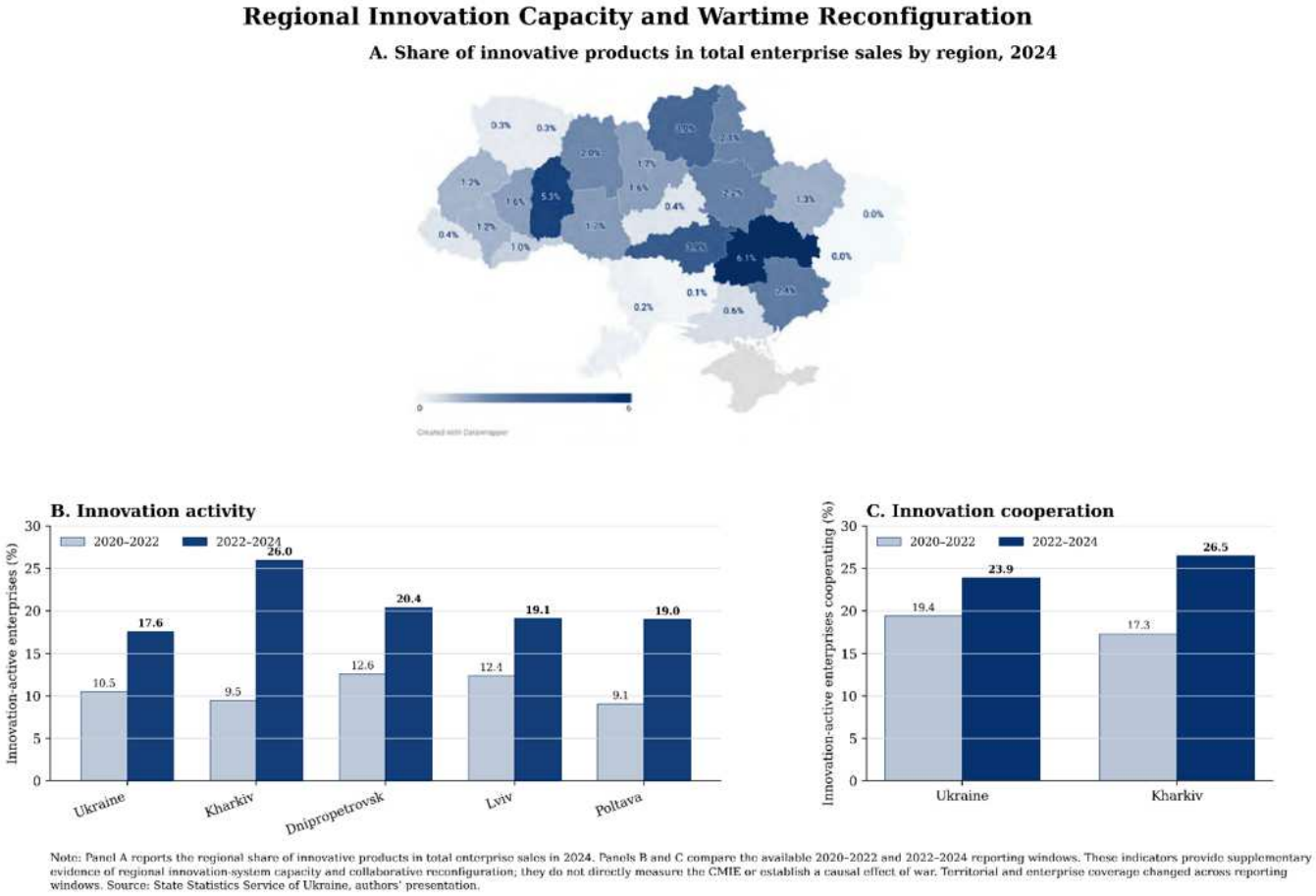


Fig. 6. Regional Innovation Capacity and Wartime Reconfiguration

Source: *Authors' presentation based on data from the State Statistics Service of Ukraine (2025).*

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- ConflictSeverityMapStyled1.png
- WIRIComponentProfilebyOblast20222025.png
- WIRIConflictSeverityWIRI.png
- WIRFNewPathDevelopmentModel4.pptx