Wartime industrial dynamics and resilience

How to promote entrepreneurship and innovation during crisis

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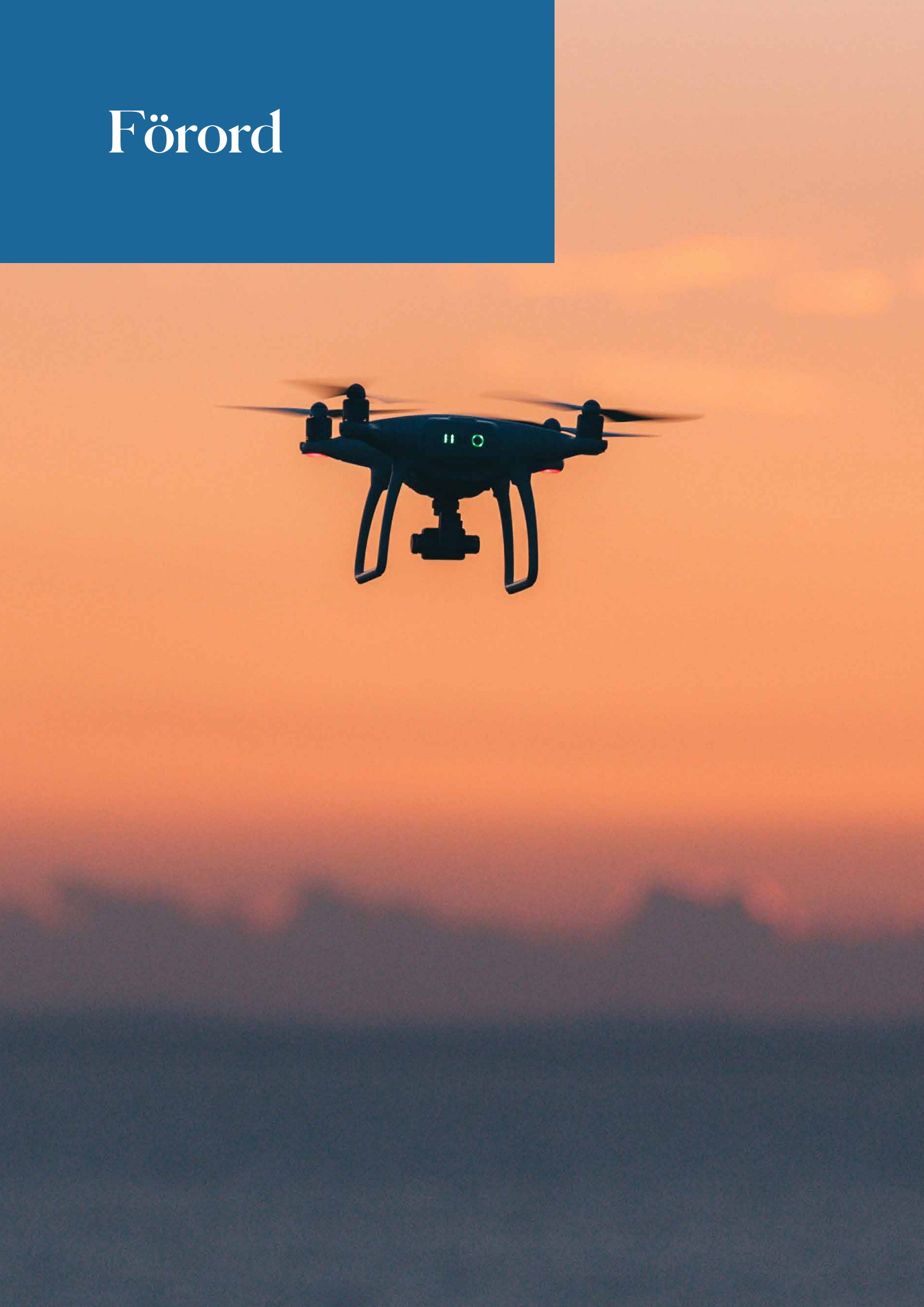


Krig prövar samhällens yttersta gränser. Samtidigt kan extrema omständigheter påskynda teknisk utveckling, omforma institutioner och driva fram nya former av samverkan mellan stat och näringsliv. Denna kunskapsöversikt analyserar Ukrainas snabba industriella omvandling under pågående krig, med särskilt fokus på framväxten av en dynamisk och strategiskt avgörande drönarindustri.

På kort tid har Ukraina utvecklat en innovations- och produktionskapacitet som inte bara möter akuta militära behov utan också omformar landets industriella struktur. Översikten belyser hur entreprenörskap, teknisk innovation och riktade statliga insatser tillsammans skapar resiliens och upprätthåller – och i vissa fall accelererar – produktion under kris och extrema förhållanden. Den visar hur nya aktörer träder in, hur regelverk anpassas i realtid och hur samverkan mellan offentlig och privat sektor kan fungera när tempot är högt och insatserna existentiella.

Översikten har framställts genom ett uppdrag från IVAs Entreprenörskapsakademi till forskarna Maryna Brychko, Blekinge tekniska högskola och Pontus Braunerhjelm,

Entreprenörskapsforum, Innehållet baseras på den forskning de har genomfört inom området.

Författarna svarar för de förslag som lyfts fram och IVA som organisation har inte tagit ställning till dessa. Entreprenörskapsakademiens styrgrupp står bakom kunskapsöversikten i sin helhet, men alla medlemmar står inte nödvändigtvis bakom alla formuleringar.

Krigets industriella dynamik och samhällets resiliens: Lärdomar från Ukraina

Svensk sammanfattning

Inledning

Världsekonomin förefaller i allt högre grad drabbas av överlappande och ihållande chocker snarare än separata och snabbt övergående kriser: finansmarknadskrisen 2008–2009, COVID-19 pandemin och Rysslands fullskaliga invasion av Ukraina utgör exempel på detta. En konsekvens är att förutsättningar och åtgärder för att bemöta kriser och upprätthålla försörjningskedjor och resiliens kan förväntas variera beroende på det specifika krisförloppet.

Även om utvecklingen i Ukraina innebär unika möjligheter att studera hur ekonomier kan agera för att produktions- och innovationssystem ska fortsätta fungera, är det inte givet att slutsatserna är desamma för andra typer av kriser. Exempelvis är en skillnad mellan Ukrainakriget och kriser i fredstid att i det senare fallet tenderar produktion, investeringar och nyetableringar att minska. I Ukrainas fall har det varit nödvändigt att öka produktions- och innovationsförmågan samtidigt som kriget härjar. Oavsett typ av kris måste dessutom varje land utgå från sina specifika förutsättningar.

I föreliggande kunskapsöversikt visar vi att långvariga krisförhållanden utmanar den traditionella förståelsen av hur inno-

vationssystem fungerar och hur industriell kapacitet bibehålls och byggs upp. I översikten redogörs för Ukrainas industriella omvandling under kriget baserat på företagsdata för perioden 1991–2025. Fokus ligger på den snabba utvecklingen av Ukrainas drönarindustri (Unmanned Aerial Vehicles, UAV:s) och vilken roll som entreprenörskapet har spelat för innovation och industriell utveckling. Ambitionen är att analysera hur samhällsresiliens kan utvecklas och stärkas när normala institutioner och marknadsmekanismer är satta ur spel.

Drönarindustrin är väl lämpad att studera för att förstå industriell omvandling och hur försörjningskedjor kan upprätthållas. Sedan 2022 har Ukraina snabbt utvecklat ett stort och diversifierat inhemskt ekosystem för drönare som omfattar tillverkning i olika led, mjukvara, ingenjörstjänster, forskning och utveckling samt civilsamhället och volontärer. Detta har skett samtidigt som det varit brist på kapital och kompetens, kombinerat med att olika samhällsfunktioner varit under extrem press.

Vi visar att Ukrainas ökade produktionskapacitet efter Rysslands fullskaliga invasion framför allt skedde genom inträde på marknaden av nya företag, en experimentell organiserad innovationsprocess och en tät, dialogbaserad kunskapsöverföring mellan

användare och tillverkare som snabbt ledde till modifierade eller nya produkter. Det var således inte redan etablerade företag som i första hand drev på dessa processer. Dynamiken kännetecknades av mångfald och selektion samt en mer geografiskt spridd produktion medförhållandevis små ekosystemstrukturer som kombinerades med digitaliserade ekosystemtjänster.

Innovation, entreprenörskap och ekosystem under press

Tidigare forskning visar att entreprenörskap och innovation minskar i kristider på grund av ökad osäkerhet, försvagade institutioner, volatil efterfrågan och stramare finansiering. I den mån innovationsaktiviteter förekommer är de i regel koncentrerade till de större och redan etablerade företagen. Samtidigt visar forskning att extrema förhållanden – som krig – kan leda till nya former av innovativ verksamhet. Inriktningen är akut problemlösning snarare än att definiera framtida strategiska marknadsmöjligheter. Det kan ses som en specifik typ av nödvändighetsdrivet, ibland kallat motvilligt, entreprenörskap.

Innovationsprocessen skiljer sig följaktligen åt i freds- och kristid. Fredstida försvarsinnovation är vanligtvis sekventiell, regle-

rad och organiserad kring långa utvecklingscykler, där urvalet så småningom sker på marknaden eller genom upphandlingsprocedurer. I en krigssituation är i stället innovation tätt kopplad till användningsmiljöer, i Ukrainas fall oftast slagfältet, där ständiga experiment, testning och modifiering av produkter sker samtidigt. Därefter styrs urvalet av demonstrerad operativ prestanda i realtid, medan regleringar och standards ofta åsidosätts.

Analysen omfattar flera branscher som tillverkar luftburna farkoster, inklusive drönare och kompletterande komponenter, där hela värdekedjan i drönarproduktion ingår: från hårdvara till FoU och prototypframställning. Vi jämför följande tre perioder: före kriget (1991–2014), en hybridkrigsfas (2014–2022) och efter den fullskaliga invasionen (2022–2025). För att få en bild av vilka som främst påverkat utvecklingen skiljer vi mellan etablerade företag, nyetablerade företag samt civilsamhälles organisationer och volontärer.

Bland resultaten märks att efter Rysslands invasion 2022–2025 fanns tre gånger så många företag registrerade som var involverade i drönarproduktion (ca 2 500) jämfört med hybridskrigsfasen (2014–2022). Även aktörer kopplade till civilsamhället

(NGO:s och volontärer) ökade. Det var främst mikroföretag (<10 anställda) som etablerades på marknaden efter invasionen (Figur A), medan det omvända gällde före 2022 (>10 anställda). Detta tyder på att den ökade produktionskapaciteten i första hand kan hänföras till företag längst ner i storleksfördelningen. Dessutom kan konstateras att tillväxten i mikroföretag som grundades efter 2022 var mer än dubbelt så stor jämfört med tidigare perioder (Figur B). Det var dock få företag som växte till fler än 49 anställda, vilket sannolikt speglar begränsningar i resurser som kapital och kompetens.

Ekosystem och kunskap

De befintliga ekosystemen förändrades avsevärt under perioden. Före 2014 dominerade traditionell tillverkning av komponenter till luftburna farkoster medan mjukvara, elektronik och ingenjörstjänster spelade mindre roll. Under hybridkrigsfasen (2014–2022) expanderade mjukvarurelaterade aktiviteter över lag i Ukraina, vilket också påverkade produktion ämnad för försvaret. Krigsutbrottet innebar att drönare, hårdvara och drönarkomponenter ökade markant men inom ett mycket mer diversifierat och sammankopplat system. FoU blev mer integrerat i produktionen samtidigt som ekosystemen blev mer modulära

och geografiskt utspridda. Anmärkningsvärt är att civilsamhälle och frivilligorganisationer blev en viktig del av dessa ekosystem, ofta med goda kontaktytor till frontlinjen och dess behov. De bidrog därmed till en snabb produktutveckling och kunskapsspridning.

Att snabbt föra in kunskap från fronten (och även andra drabbade delar av samhället, till exempel rörande energi) är en nyckelfaktor för en framgångsrik innovationsprocess. När innovationer används i skarpt läge skapas ny kunskap som direkt kan återkopplas för att vidareutveckla en produkt eller för att ta fram en ny prototyp. Det betyder att enheter verksamma vid fronten, stridserfaren personal, volontärer, m fl, blir centralt viktiga som kunskapsbärare och validering av kunskap. I Ukraina har slagfältet fungerat som en epistemisk institution: vid militära insatser ges återkoppling om prestanda, sårbarheter och om eventuella modifieringar i produkten bör göras. Kunskapsspridningen kan ytterligare förstärkas genom digitala kommunikationskanaler, omvänd ingenjörskonst av beslagtagen utrustning och snabb personalrotation som kan stärka spridning av tyst, erfarenhetsbaserad kunskap.

Offentlig upphandling och statliga stöd

Offentlig upphandling har utgjort en central länk mellan statens efterfrågan och inhemsk produktion. Trots ett ökat deltagande av mindre företag är det främst större etablerade företag som tilldelats offentliga kontrakt. Det är också en betydligt större andel av de etablerade företagen – små som stora – som lämnat in anbud. Sammantaget visar det sig att en liten delmängd av företagen har stått för en oproportionerligt stor andel av de vunna anbuden. Detta innebär att även om offentlig upphandling formellt varit öppen för nya aktörer, har få lämnat in anbud och än färre har lyckats vinna en upphandling. I stället har företag med större administrativ kapacitet och erfarenhet varit vinnare i dessa anbudsprocesser.

Statens insatser för att stödja företag har således delvis skett genom offentlig upphandling, men också genom kapitalstöd, antingen efter ansökan eller genom att vissa aktörer erhållit direktfinansiering från staten. I Ukrainas fall har förmågan att förhållandevis snabbt identifiera företag med god potential förbättrats betydligt under kriget. Dessa företag har i regel också erhållit någon slags form av stöd. Samtidigt finns det tydliga tecken på koncentration även i detta fall: företag som direkt-

finansierats av staten har en större sannolikhet att gå segrande ur offentliga upphandlingsprocesser. Detsamma gäller företag som tidigare sökt och tilldelats statliga stöd. Likaså visar analysen att etablerade företag tilldelas betydligt högre belopp och överlag är mer involverade i transaktioner med offentlig sektor.

Civilsamhällets roll

I Ukraina har organisationer kopplade till civilsamhället, NGO:s och volontärer, bidragit på en rad olika sätt. Dels har de varit involverade i produktion och systemintegration av drönare, men också när det gäller utbildning och insamling av kapital för att finansiera drönarproduktion. Volontärer har bidragit med tusentals monteringsenheter som ofta samordnats med frontlinjens behov.

Digitala civila (och militära) plattformar etablerades tidigt som gjorde det möjligt för civila att bidra med operativ information och effektivt omvandla samhället till ett distribuerat sensornätverk för att bygga resiliens. Utbildningsinitiativ som initierats av NGO:s och volontärgrupper innebär att brister i tillgången på humankapital, exempelvis vad gäller drönaroperatörer och tekniker, har lindrats.

Författarnas reflektioner

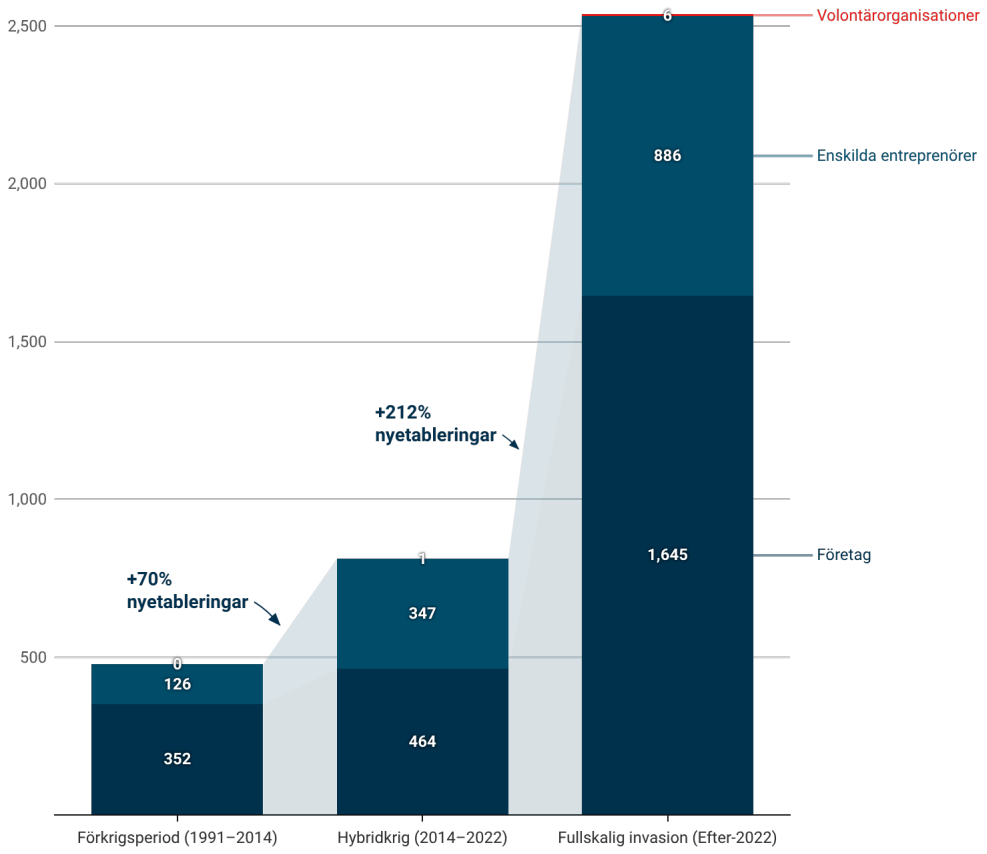
Sammanfattningsvis illustrerar innovationssystemen kring den ukrainska drönarproduktionen en krigstidsindustriell logik som skiljer sig från fredstida modeller. Produktiv kapacitet har främst uppstått genom snabbt marknadsinträde av nya aktörer. Experiment har skett på mikronivå, kombinerat med modulära och geografiskt distribuerade produktionsstrukturer. Kontinuerlig interaktion mellan användare och innovatörer/entreprenörer har varit avgörande för framgångsrik innovation. Samtidigt förefaller staten ha lyckats relativt väl med att identifiera potentiellt strategiskt viktiga produkter i tidiga skeden. Kombinerat med offentlig upphandling som sker hierarkiskt och stegvis har företag som kunnat skala upp sin produktion selekterats fram. Sammantaget visar detta hur industriella system har omorganiserats när anpassning måste ske kontinuerligt under extrem osäkerhet.

Författarnas slutsatser i åtta punkter

1. Motståndskraft är en omvandlings- och flexibilitetsförmåga, inte en lagrad kapacitet

Den snabba expansionen av Ukrainas drönarproduktion har främst skett genom nyetableringar av företag efter krigs-

FIGUR A: Nya företag och enskilda entreprenörer i Ukrainas drönarindustri fördelat på tre tidsperioder.



utbrottet 2022. Urval av produkter som staten upphandlat baseras på användningsbaserad validering. Slutsatsen är att motståndskraft baserad i produktionsförmåga i första hand inte bör förstås som lagrad kapacitet inom etablerade företag. Snarare handlar det om kapacitet att aktivera, testa och selektivt skala upp produktion i innovativa, unga och mindre företag. Flexibi-

litet och omställningsförmåga är avgörande. Prestandan i användning av företagens produkter bör styra upphandling och tillväxt, inte företagens storlek eller ålder.

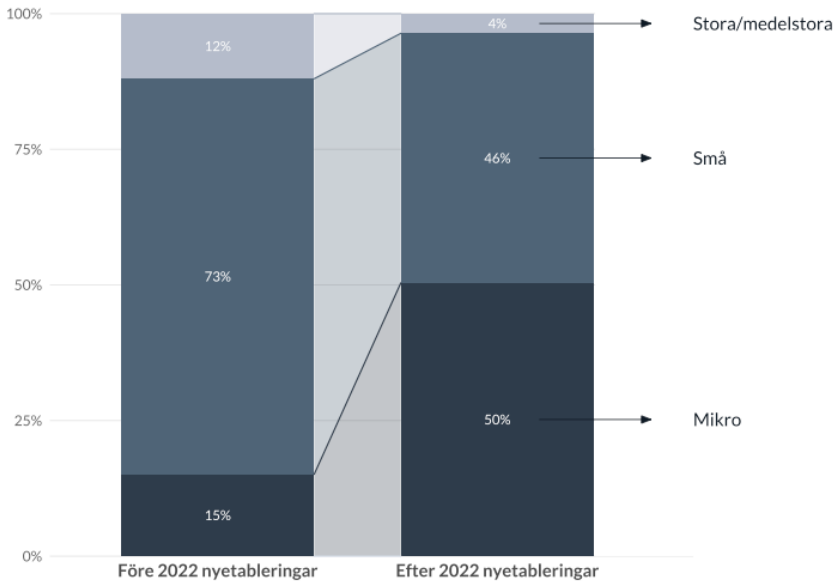
2. Uppskalning av verksamheten kräver riskdelning

Även om data för Ukraina visar att företagen snabbt skalade upp verksamheten har bestående flaskhalsar hindrat övergång till en storskalig produktion. Tillgång till kapital, infrastruktur samt leveranskedjornas sårbarhet har inneburit betydande begränsningar och nya produktionsförutsättningar har uppstått. I förlängningen kan det medföra att innovativa företag som inte lyckas skala upp verksamheten inte heller kan leverera på sikt, dvs kapacitetsbrist kan uppstå av kritiskt viktiga produkter. Staten bör redan i fredstid vidta åtgärder för att minska potentiell resursbrist, liksom risk mer generellt, för att företagen ska kunna nå industriell skala och ökade volymer.

3. Distribuerad och modulär produktion ökar överlevnads- och anpassningsförmåga

Ekosystem som stöttar Ukrainas drönarproduktion har förskjutits från geografiskt koncentrerade strukturer dominerade av ett fåtal traditionella tillverkningsföretag, till ett mer modulärt, geografiskt distribuerat och sammankopplat system. En sådan struktur

FIGUR B: Fördelning av företag på mikroföretag (0–9 anställda), småföretag (10–49 anställda) och företag med fler än 49 anställda.



innebär att olika tillverkningsenheter som slås ut lättare kan kombineras och ersättas av andra. Sårbarheten för riktade attacker liksom försörjnings- och produktionsstörningar minskar. Politiken bör därför främja leverantörsredundans, distribuerad produktion och standardisering av vitala komponenter som lätt kan ersättas.

4. Utökad offentlig upphandling är viktigt men bör i högre grad omfatta mindre företag

Trots att Ukraina genomfört reformer som bidragit till ett mer flexibelt upphandlingsförfarande har nya och mindre företags

andel av vunna kontrakt förblivit betydligt lägre än för etablerade företag. Relativt få företag vinner fortfarande de flesta kontrakten. Även om innovationssystemet uppmuntrar inträde och experiment med nya produkter och tjänster, gynnar de formella upphandlingssystemen etablerade företag med administrativ kapacitet, erfarenhet och rutiner. Även om förmågan hos upphandlaren att identifiera innovativa och relevanta produkter i en krigssituation stärkts finns en förbättringspotential. Staten bör underlätta för små och medelstora företag samt entreprenörer att kunna delta i offentlig upphandling, antingen genom enklare procedurer eller genom att bistå mer direkt (med ansökan, dokumentation, etc.). Upphandling bör struktureras med inledande pilotkontrakt som efter utvärdering eventuellt följs av ökade kontraktsvolymer och uppskalning. Optimalt fungerar upphandling både som en lärandeprocess och ett filter.

5. Statliga stöd bör ske stegvis och enligt en tydlig struktur

Tillgång till stöd och support för ukrainska företag under kriget kan beskrivas som en sekventiell process där olika aktörer har olika roller. De svåraste och mest ansvarskrävande åtagandena har huvudsakligen tilldelats redan etablerade företag. Denna fördelning av roller där snabbt igenkännande och inkludering av potentiellt viktiga leverantörer kombineras med en delege-

ring av större satsningar till erfarna och ansvarstagande aktörer har visat sig fungera förhållandevis väl. Politiken bör därför utveckla mekanismer som i), möjliggör att nya aktörer tidigt kan inkluderas i det försvarsindustriella systemet, ii) att kvalitet och prestanda snabbt valideras, iii) att erfarna aktörer med visad kapacitet också möjliggör för nya aktörer att skala upp sina verksamheter.

6. Civilsamhällesaktörer och volontärer viktiga för resiliens

Volontärer och civilsamhälles aktörer (NGO:s, dvs non-governmental organisations) är i regel få till antalet men dess roll för produktion, innovation och finansiering har likväl varit betydande i Ukraina. Dessa aktörer har snabbt utvecklat produkter i linje med behovet vid fronten, ofta genom dialogbaserade och iterativa processer, vilket påskyndat kunskapsspridning och produktrelevans. Resiliensen har ökat när statliga- och privata aktörer varit överbelastade. Politiken bör erkänna och uppmuntra den viktiga roll som dessa aktörer spelar i såväl freds- som krigstid.

7. Digital infrastruktur möjliggör decentraliserad innovation och nya marknader

Ukrainas innovationsekosystem under kriget visar att när regeringen tillhandahåller delad digital infrastruktur (plattformar) och

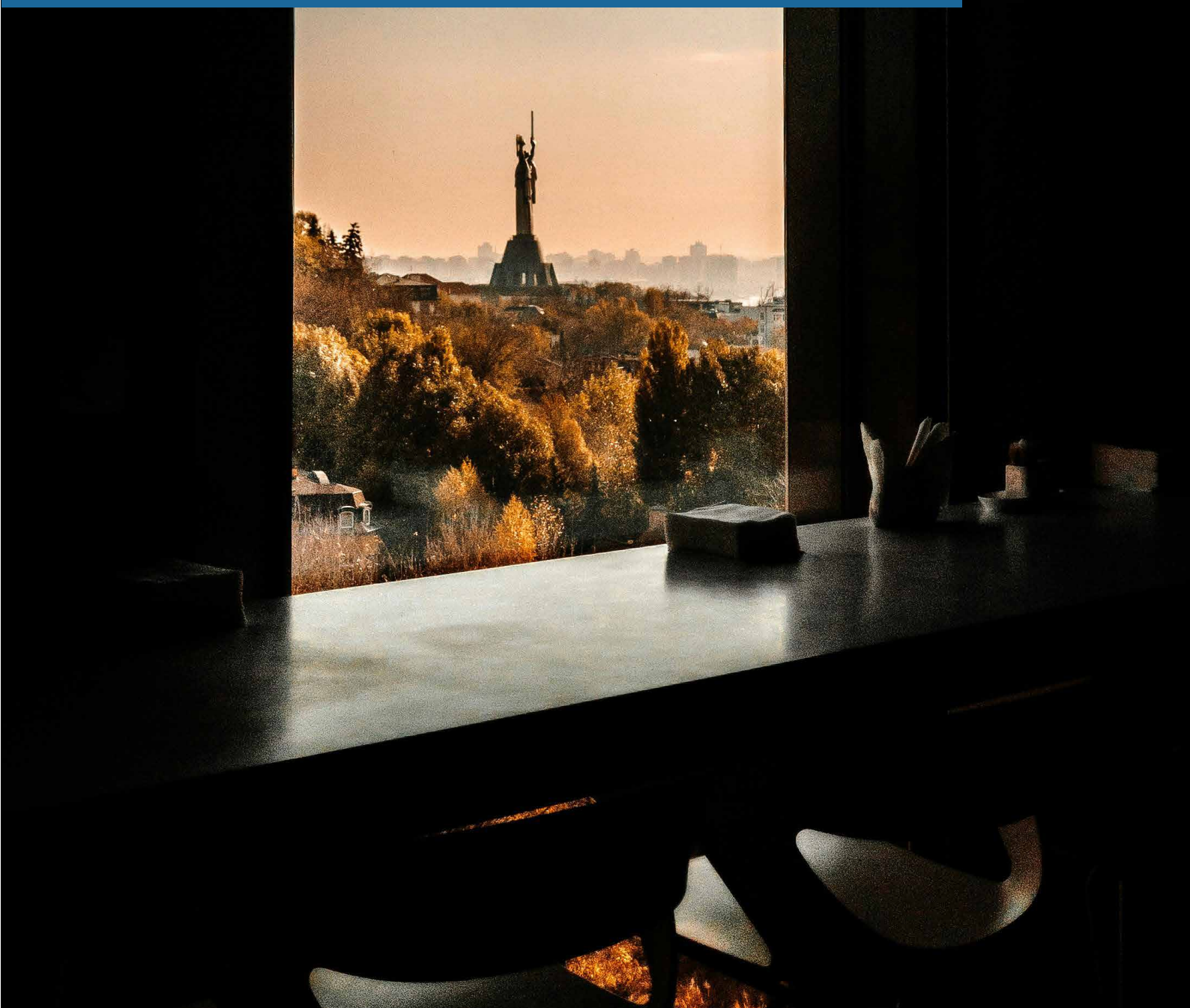
tydliga operativa ramar, kan innovation decentraliseras samtidigt som strategisk tillsyn och koordinering upprätthålls. Digitala plattformar, såsom Brave1, DOT-Chain Defense och Zbroya Smart Force, har inneburit att nya marknader skapats som möjliggör inträde av nya företag samt test av nya lösningar och genomföra experiment. Snabb kunskapsöverföring och feedback har varit en förutsättning för att operativt effektiva lösningar snabbt kunnat skalas upp eller modifieras, dvs innovation sker praktiskt taget i realtid. Lärdomen är att staten redan bör idag verka för att den typen av plattformar etableras.

8. Feedback från frontlinjen måste generera ett kontinuerligt kunskapsflöde

Ukrainas erfarenheter visar att dialog med frontlinjen varit centralt viktig för att för att stödja anpassning och modifiering av vapen och annat krigsmaterial. Detta har dock endast delvis integrerats i formella upphandlings- och uppskalningsprocesser. Lärdomen är att den typen av återkoppling behöver institutionaliseras i tydliga former för att systematiskt informera om prestanda, underlätta validering och urval och därmed kunna upphandla effektivare. En förutsättning är tillgång till säkra kommunikationskanaler vilket staten proaktivt bör verka för.

Introduction

»Total defense and industrial preparedness cannot be designed solely for short-lived emergencies followed by a return to peacetime equilibrium.«



Over the past two decades, advanced economies have increasingly operated under conditions of persistent disruption rather than prolonged stability. The global financial crisis, the European sovereign debt crisis, the COVID-19 pandemic, and the current high-intensity war in Europe have each created enduring pressures on economic systems. Rather than being isolated incidents followed by lengthy recoveries, these crises have occurred in a near-continuous sequence. Periods of uncertainty and systemic stress are no longer episodic interruptions of "normal" economic conditions, but an increasingly durable context shaping how governments, businesses, and innovation systems operate. When shocks happen frequently, overlap, and last a long time, institutions built for temporary disruptions find it hard to adapt. As a result, the line between crisis management and peacetime policy has become increasingly blurred, raising questions about whether institutions designed for temporary shocks remain fit for environments characterized by sustained disruption.

From this perspective, Russia's full-scale invasion of Ukraine should not be seen as an isolated event but as an extreme manifestation of a broader pattern of ongoing uncertainty. What distinguishes the Ukrainian case is not only the severity

of the shock, but also the speed and scale with which industrial and innovation systems were reconfigured while the crisis was ongoing. Innovation, production, and organizational changes did not wait for stability or recovery, they occurred simultaneously with the disruption.

Ukraine's wartime Unmanned Aerial Vehicles (UAV) ecosystem offers insight into how innovation systems function when crisis conditions persist, and persistent institutional adjustment cannot be postponed. The swift rise of new producers, the integration of civilian and military capabilities, and the move toward use-based validation reflect responses to an environment in which uncertainty is not temporary but structural. These dynamics illuminate how industrial organization, entrepreneurship, and state coordination evolve when adaptation must occur continuously rather than episodically.[1] For Sweden and other European countries, this reframing has important

1 Note that according to Ukrainian legislation an individual entrepreneur is a person registered to conduct business activity without forming a separate legal entity. An entrepreneur operates under personal legal liability, does not possess independent legal personality distinct from the individual, and is subject to simplified registration, taxation, and reporting.

implications. Total defense and industrial preparedness cannot be designed solely for short-lived emergencies followed by a return to peacetime equilibrium. Instead, they must accommodate prolonged periods in which uncertainty, security pressures, and systemic disruption shape innovation incentives and organizational behaviour. Understanding how Ukraine's innovation system adapted under sustained crisis conditions can therefore inform how European industrial and innovation policies might be structured for a world in which "normal times" are increasingly rare.

This report builds directly on earlier studies of Ukraine's drone industry by the authors.[2] It provides an empirical analysis of how entrepreneurship, innovation, and industrial capacity emerge under wartime conditions, using firm-level data on Ukraine's UAV ecosystem from 1991 to 2025. It shows that crisis-driven production capacity is generated primarily through rapid entry and use-based learning rather than through the scaling of incumbent firms. The report documents how selection shifts from ex ante administrative screening to ex post validation

2 Braunerhjelm, P., & Brychko, M. (2025); Brychko, M., & Braunerhjelm, P. (forthcoming).

through operational performance, with procurement and public funding acting as stepwise escalation mechanisms. By conceptualizing resilience as a system-level capability to absorb, test, and selectively scale new actors, the report derives actionable lessons for designing innovation and defense institutions that remain effective under prolonged crisis conditions.

Background and previous research

»Crises increase uncertainty and risk, complicating the evaluation of entrepreneurial opportunities and discouraging long-term investment.«

Innovation systems and entrepreneurship under stress and crisis

A large body of research in economics, innovation studies, and policy analysis emphasizes that crises generally constrain entrepreneurship and innovation rather than stimulate them (OECD, 2012; Howell et al., 2020). Periods of war, violent conflicts, financial crisis, pandemics, or other severe systemic shocks are typically associated with heightened uncertainty, capital scarcity, disrupted supply chains, and weakened institutions, all of which raise entry barriers and reduce incentives for innovative investment. Empirical studies of conflict-affected and post-conflict economies similarly document declines in firm entry, innovation, and growth, particularly among small and medium-sized enterprises (Miklian & Hoelscher, 2022; Naudé, 2007).

Within this literature, the decline in entrepreneurial activity during stress and crises is commonly explained by three mechanisms. First, crises increase uncertainty and risk, complicating the evaluation of entrepreneurial opportunities and discouraging long-term investment. Second, formal institutions that support innovation, such as financial markets, public procure-

ment systems, and intellectual property regimes, often weaken or become dysfunctional during crises, limiting firms' ability to commercialize new technologies. Third, demand conditions become volatile and difficult to forecast, undermining incentives to develop or scale new products, particularly in technologically complex industries. These mechanisms imply that innovation systems under stress tend to contract, prioritizing survival and cost minimization over experimentation.

Beyond uncertainty and demand volatility, capital constraints constitute another relevant channel through which crises reshape innovation activity. While much of the empirical evidence on this mechanism originates from studies of economic and financial downturns, its core logic is highly relevant to wartime conditions. Periods of severe stress are typically associated with tighter credit conditions and increased risk aversion among financial intermediaries, reducing access to external finance for innovation, particularly for young and small firms (Paunov, 2012; Spatareanu et al., 2019). Evidence from banking and sovereign debt crises shows that sectors reliant on external finance experience disproportionately large declines in R&D investment, reinforcing financing barriers during periods of acute uncertainty and disruption (Friz & Günther, 2021; Hardy & Sever, 2021).

As a result, innovation activity tends to shift toward larger and older firms, which are better able to rely on internal resources and accumulated capabilities to sustain innovation under financial stress (Archibugi et al., 2013; Paunov, 2012). This pattern reflects a process of creative accumulation, in which incumbent firms continue to innovate incrementally along established technological trajectories, while smaller and newer firms are more likely to scale back innovation due to binding liquidity constraints (Baker & Nelson, 2005; Nelson & Winter, 1982; Schumpeter, 1942).

However, crises and heightened uncertainty do not eliminate innovation altogether; rather, they change who innovates, why innovation occurs (the underlying motivations and incentives), and how it is carried out (the methods used). Research on opportunity creation under uncertainty emphasizes that entrepreneurial action does not always follow from deliberate opportunity recognition, but may instead emerge from actions taken in response to pressing constraints (Alvarez & Barney, 2007). In such contexts, innovation is often driven less by commercial ambition or strategic foresight than by urgent necessity. Building on this insight, Banks (2013) conceptualizes reluctant entrepreneurship as innovation undertaken not because actors

seek to exploit market opportunities, but because failing to act would entail unacceptable operational, social, or survival costs. Crisis conditions can therefore compel individuals and organizations that would otherwise remain outside entrepreneurial activity, such as engineers, professionals, volunteers, or small workshops, to mobilize their existing skills and knowledge in novel ways (Banks, 2013).

Crisis scholarship further indicates that extreme shocks push new non-traditional actors into entrepreneurial roles, turning constraints into opportunities for innovation (Audretsch et al., 2025; Krishnan et al., 2022; Lee et al., 2024). At the same time, innovation can emerge from recombining existing skills and capabilities in new ways, even without formal R&D investments (Acs et al., 2004; 2009; Braunerhjelm et al., 2010). Evidence from post-conflict contexts also highlights the emergence of informal coordination mechanisms, civic initiatives, and non-market resource allocation, which serve as partial substitutes for weakened formal institutions and enable continued innovation despite systemic disruption (Naudé, 2007). From an innovation policy perspective, these forms of crisis-induced innovation are best understood as necessity-driven, relying on adaptive recombination and rapid learning rather than formal

R&D, while often generating anticipatory and potentially disruptive effects as they reshape existing technological and organizational arrangements.

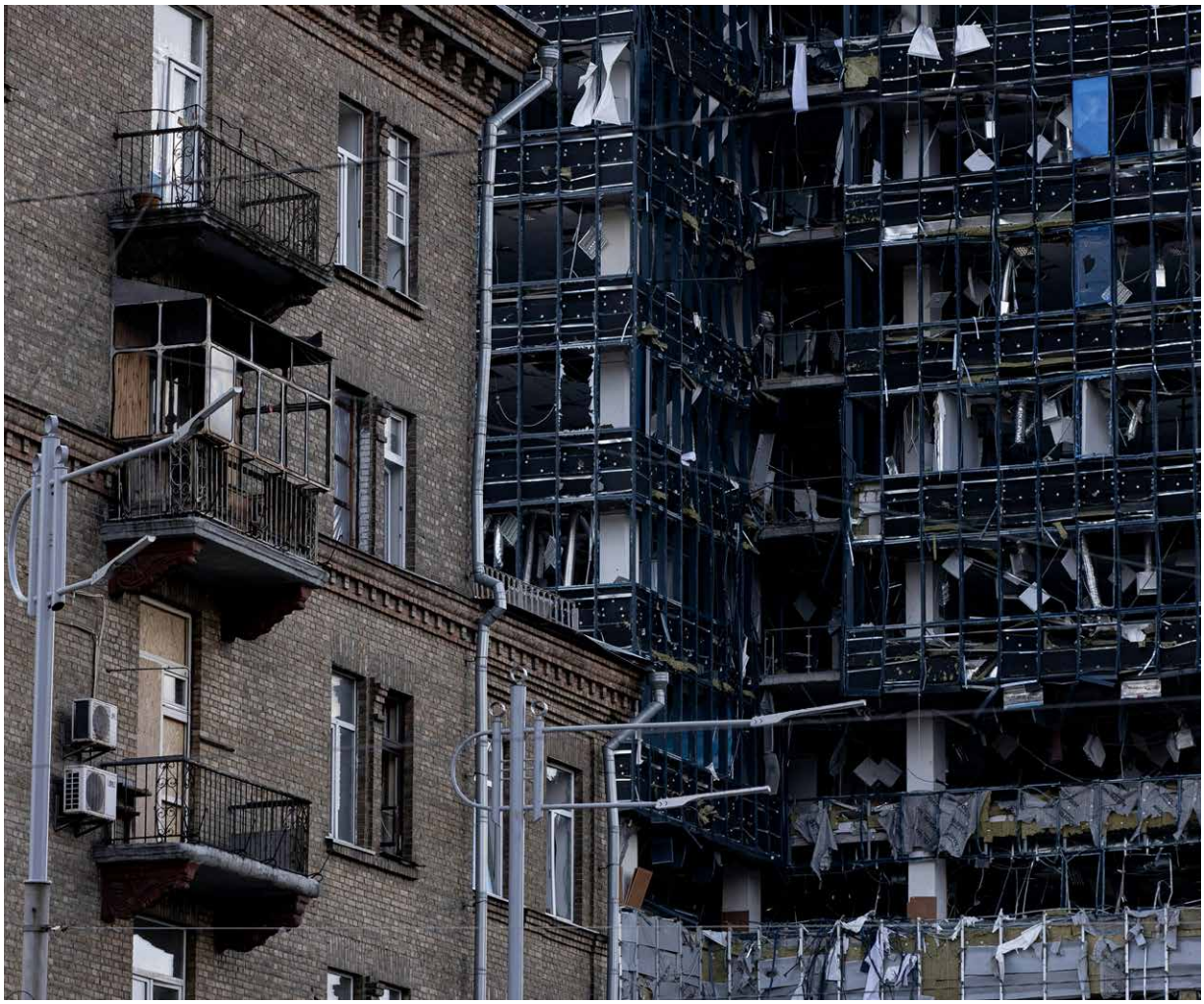
Despite growing attention to innovation under crisis conditions, current evidence provides limited guidance on how innovation systems operate during ongoing high-intensity conflict. Most empirical analyses focus on pre-crisis conditions or post-conflict recovery, implicitly treating war as an external shock rather than as an environment in which learning, experimentation, and selection continue in real time. This limitation is particularly acute in defense-related sectors, which in peacetime are typically characterized by centralized procurement, long development cycles, and strong incumbent advantages.

Wartime versus peacetime innovation and industrial logic

A comparison between peacetime and wartime innovation systems highlights that the difference is not only in speed or intensity, but also in a shift in the industrial logic that governs objectives, time horizons, coordination, and selection (Berthelsen, 2025). In peacetime, especially in defense and other complex

industries, innovation is typically organized around efficiency, reliability, and cost control, reflecting the need to manage high fixed costs, regulatory requirements, and long development cycles (Mowery, 2010; Nelson & Winter, 1982). These objectives are embedded in multi-year planning and contracting structures, where firms optimize performance against relatively stable specifications and procurement rules.

Within this peacetime logic, innovation processes are predominantly sequential. Research and development, testing, certification, procurement, and deployment are organized into distinct stages, with learning primarily occurring before deployment and feedback from use incorporated only after formal evaluation cycles are completed. Selection therefore occurs largely ex ante through administrative screening, regulatory compliance, and centralized procurement procedures. This structure favors incumbent firms with accumulated technological capabilities, established compliance routines, and the organizational capacity to absorb long development timelines, reinforcing concentrated and hierarchical industrial structures (Bellais & Guichard, 2006; Mowery, 2010; Nelson & Winter, 1982).



Wartime conditions alter these organizing principles in fundamental ways. Rather than optimizing against predefined specifications, innovation becomes oriented toward operational effectiveness under rapidly changing and adversarial conditions. Time horizons compress, and the feasibility of linear development pipelines diminishes. As a result, innovation processes become non-linear and tightly coupled with use, as experimen-

tation, deployment, and modification occur simultaneously (Ruttan, 2006). In wartime innovation systems, selection moves from ex ante administrative evaluation toward ex post validation through operational use. Technologies and producers are retained, scaled, or abandoned based on demonstrated performance under real conditions, rather than on anticipated performance or formal certification (EU, 2025).

The role of the state also differs across these regimes. In peacetime, the state primarily acts as regulator and purchaser (Horner, 2017), defining requirements in advance and enforcing compliance through procurement and certification. In wartime settings, the state's role shifts toward orchestration (Berk, 2018; Berk, 2019) and validation, facilitating experimentation, enabling rapid feedback between users and producers, and scaling solutions that demonstrate operational value. Drawing from military innovation (Rosen, 2019), states adapt their institutional practices to enable more dynamic, experimental approaches during high-stakes periods, particularly by creating structures that support rapid learning and solution scaling.

Data and scope

»This report draws on registry-level data to trace the development of Ukraine's drone and defense technology sector from 1991 to 2025.«

This report draws on registry-level data to trace the development of Ukraine's drone and defense technology sector from 1991 to 2025. The analysis focuses on organizations involved in the design, production, and integration of unmanned aerial vehicles and related systems.

As a starting point, the analysis implements data on Manufacture of air and spacecraft and related machinery (NACE[3] 30.30) as the core industrial identifier. Within Ukraine's statistical system, this category provides the most precise proxy for UAV and UAS (unmanned aircraft system) manufacturing. Because the national Ukrainian business registry does not distinguish between manned and unmanned aircraft, it includes both conventional aerospace manufacturers and a rapidly expanding set of dual-use UAV companies involved in the manufacturing, assembling, and integration of UAVs following the onset of the full-scale invasion. As a result, this category captures a heterogeneous but strategically relevant segment of firms operating at the intersection of civilian aerospace and military drone procurement.

3 The version of NACE Revision 2 (published 2006) was used, https://ec.europa.eu/eurostat/web/nace

To reflect the distributed and cross-sectoral nature of defense innovation under wartime conditions, the dataset extends beyond core aerospace manufacturing. Entities were additionally drawn from complementary industrial domains (under complementary NACE categories) that contribute critical inputs to UAV development, including electronics, software, propulsion, research and development, maintenance, and security operations. Entities were included in the dataset only if the following two conditions were met: (1) their main activity code (primary NACE classification) had to fall within one of the UAV ecosystem sectors listed in Appendix A (Table A.1); and (2) their secondary code had to include NACE 30.30, ensuring direct functional linkage to aircraft-related production. Furthermore, entities were added when publicly available documentation, such as official registries (procurement records) or media sources, confirmed active involvement in drone design, manufacturing, system integration, or experimental testing.

Based on this approach, the Ukrainian UAV ecosystem is organized into eight functional tiers reflecting different roles within the value chain:

- The first tier comprises dual-use aerospace manufacturing, comprising 2,176 entities producing airframes, propulsion systems, and related components for both civilian and military use.
- The second tier includes 94 entities involved in armament and defense manufacturing, such as developing loitering munitions, warhead integration, and combat UAV systems.
- The third tier covers 415 producers of hardware subsystems and components, which supply avionics, optics, power systems, and communication modules.
- The fourth tier includes 681 organizations specializing in software and data systems that develop autopilot algorithms, flight control software, navigation systems, swarm-coordination tools, and telemetry data platforms.
- The fifth tier includes 193 research and development (R&D) and prototyping entities involved in applied research, experimental UAV development, and testing.
- The sixth tier comprises 268 engineering, testing, training, and maintenance providers that offer certification, flight

testing, drone operator training, technical consultancy, and repair services.

- The seventh tier captures a small number of civic and volunteer production initiatives, which, despite their legal status, directly contribute to design, production, and knowledge transfer.
- The eighth tier includes 16 security and defense actors, spanning state, private entities, and individual entrepreneurs involved in the supply, maintenance, and production of military and technical security technologies, including drones, electronic warfare systems, radar systems, etc.

This classification reflects Ukraine's wartime industrial transformation, where commercial enterprises, research organizations, and civic initiatives operate within a tightly integrated innovation system. The analysis comprehensively encapsulates the entire spectrum of epistemic institutions involved in the production, validation, and commercialization of UAV-related knowledge during wartime conditions; therefore, it represents the full UAV value chain rather than focusing narrowly on final assemblers.

In the analysis, we integrate formal industrial classification with open-source verification, capturing both official industrial activities and informal production networks, while intentionally excluding purely fundraising or humanitarian efforts. Although numerous non-governmental and volunteer organizations currently contribute significantly to Ukraine's drone ecosystem, particularly in areas such as financing, procurement, and logistical support, this study focuses on those entities that demonstrably facilitate knowledge creation and technological advancement. Therefore, the database includes organizations publicly confirmed to be involved in drone design, assembly, or technical experimentation, such as the charitable organization Wild Hornets,[4] NGO Aerorozvidka,[5] and others, rather than a broader range of financial and volunteer support activities.

To analyze how Ukraine's drone entrepreneurship and innovation evolved over time, firm-level data were organized into a longitudinal panel covering the period 1991–2025. Company registration records extend back to the early years of Ukraine's

4 A miltech company "Wild Hornets" specializing in the development and production of combat drones, https://wildhornets.com/en/

5 NGO "AEROROZVIDKA", https://aerorozvidka.ngo/en

independence, enabling analysis of long-term patterns of industrial dynamics and wartime resilience, including entry, persistence, and structural change in the industrial base. Historical information was primarily sourced from YouControl Market, which offers comprehensive coverage of firm registrations and legal statuses. The database was further expanded to include the state scientific and research enterprise Konesk, established in 1990 and retained in the dataset because it has continued to operate throughout Ukraine's post-independence period.

To reflect the profound impact of security conditions on industrial organization and state-industry relations, the analysis distinguishes between three broad phases:

- Pre-war baseline (1991–2014): a period of peacetime industrial development characterized by conventional market entry, limited state involvement, and slow technological diffusion in defense-related activities.
- Hybrid war phase (2014 – 23.02.2022): a phase of partial mobilization and early regulatory adaptation following Russia's annexation of Crimea and first invasion in eastern Ukraine (Donbas area). During this period, informal collaboration,

volunteer initiatives, and selective deregulation began to reshape the defense innovation landscape.

- Full-scale invasion period (after 24.02.2022): a phase of nationwide mobilization and extensive regulatory adjustment after February 24, 2022, marked by rapid expansion of state procurement, public funding, and coordination mechanisms to support wartime production and battlefield needs.

In addition to this temporal division, firms are grouped into two entry cohorts that reflect differences between those influenced by pre-war institutional conditions and those shaped by war-time mobilization and emergency regulatory regimes.

- Pre-2022 incumbents: Firms registered before the full-scale invasion, including both long-established producers and organizations that entered during the hybrid war period. These entities typically built up their technical capabilities, networks, and administrative capacity over time.
- Post-2022 entrants: Firms established after February 24, 2022, in direct response to wartime demand. This cohort reflects the rapid expansion of production capacity during crisis conditions and includes many newly established, highly adaptable producers responding to battlefield needs, operating with limited prior experience in formal state procurement or funding systems.

For a detailed account of the data and the methodological approach, we refer the reader to Appendix B.[6]

6 Data management and analysis were performed using RStudio, version 2025.09.2+418. Visualization was conducted using RStudio and the Datawrapper online platform. For more details on methodology and measurement indicators, refer to Appendix B.

Wartime industrial transformation: Ukraine's UAV ecosystem

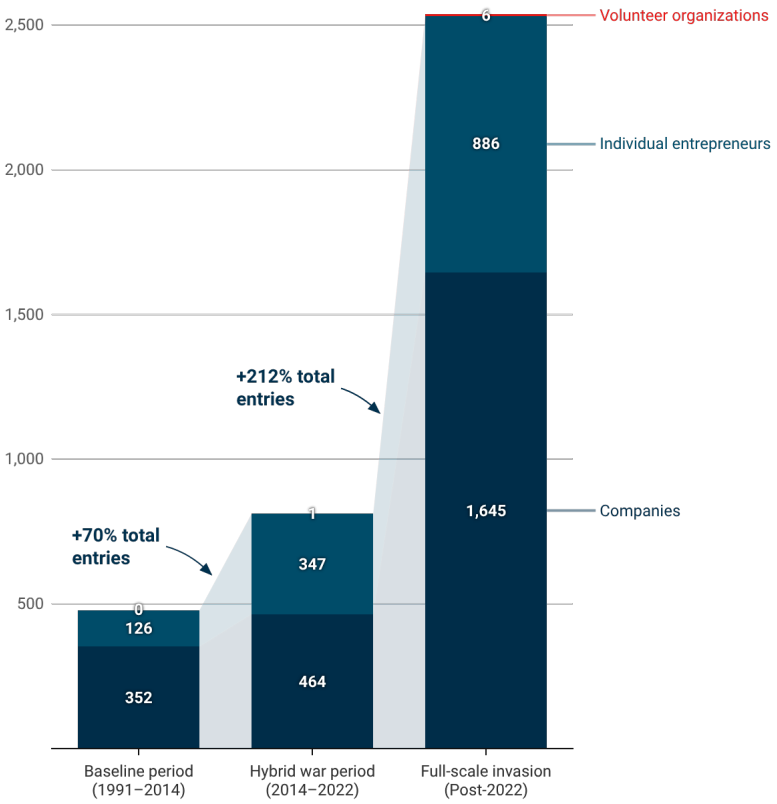
»Operational relevance, technical adaptability, and the ability to incorporate frontline feedback became key factors for entry, along with, but often ahead of, financial capacity.«

Trajectories of firms and entrepreneurs

In severe crises, industrial development rarely follows the incremental and path-dependent trajectories typically observed in peacetime industrial organization. Instead, crisis conditions tend to compress time horizons and alter the mechanisms through which productive capacity emerges. As mentioned above, new firm activity is less likely to originate from long-term R&D programs or university-based spin-offs, and more likely to arise from rapid recombination of existing skills, equipment, and organizational capabilities in response to immediate battlefield operational needs. Ukraine's experience since 2022 indicates a substantial reconfiguration of entry conditions during wartime mobilization.

Figure 1 documents these dynamics in the Ukrainian UAV ecosystem across three periods: the pre-war baseline (1991–2014), the hybrid war phase (2014–2022), and the period following the full-scale invasion (post-2022). The data cover all formally registered entities engaged in UAV-related activities, including incorporated firms (limited liability companies and joint-stock firms), individual entrepreneurs, and volunteer or charitable organizations involved in the design or production of UAVs. The

FIGURE 1: Entry dynamics of the UAV ecosystem. *Note: Distribution of registered entities before and during wartime periods.*



data reveals a clear structural break after 2022, when the number of new entrants more than tripled, from 812 entities during the hybrid-war phase to 2,537 during the first three years of the full-scale invasion.

Prior to 2014, entry into the aerospace and defense-related production industry was restricted and mainly dominated by well-established companies, some of which inherited capabilities from the Soviet industrial system. Private entry remained modest, and civic and volunteer groups played almost no part

in production. Following the annexation of Crimea and the outbreak of hostilities in eastern Ukraine (Lugansk and Donetsk regions), entry gradually increased, partly fueled by smaller electronics and software companies experimenting with dual-use technologies. However, these activities mostly remained peripheral to the main defense manufacturing system.

The period since 2022 marks a distinct stage of industrial mobilization. More than 2,500 entities registered within a short period, including 1,645 private companies, 886 individual entrepreneurs, and a small number of formally registered volunteer organizations. This pattern reflects a sharp reduction in effective entry barriers under wartime conditions. Many new producers emerged at a small scale or in informal settings and later formalized to interact with military units, procurement systems, or funding programs. In this environment, operational relevance, technical adaptability, and the ability to incorporate frontline feedback became key factors for entry, along with, but often ahead of, financial capacity.

Russia's full-scale invasion of Ukraine has reshaped the industrial structure and innovation pathways, especially in Ukraine's drone industry. Ukraine's UAV sector shifted from relying on

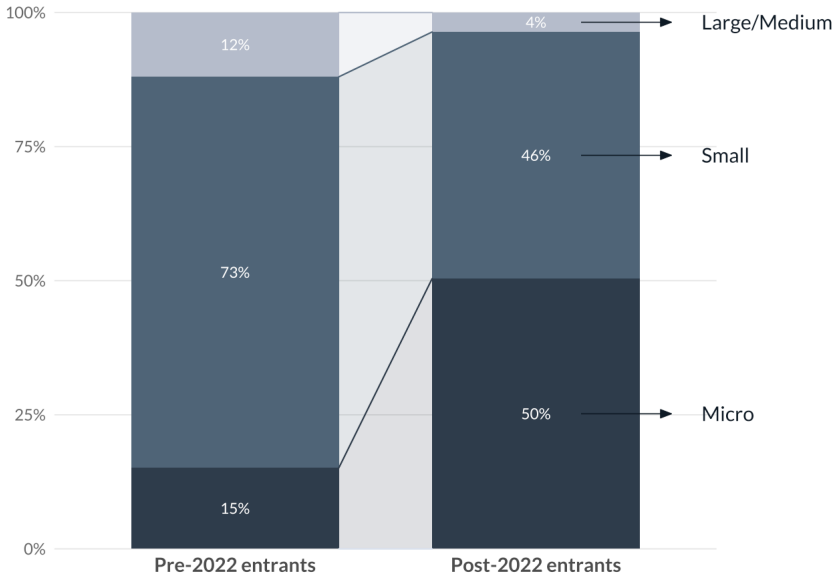


FIGURE 2: Distribution of entry sizes by cohort.

imports to a distributed domestic manufacturing system marked by rapid learning cycles, decentralized experimentation, and close collaboration between battlefield users and producers. Therefore, industrial resilience under extreme stress depends not only on protecting incumbent capacity but also on the ability of institutions to absorb, legitimize, and scale up newly emerging producers when conventional market mechanisms are disrupted.

Figure 2 illustrates the distribution of firm sizes at entry by entities established before and after the full-scale invasion. For pre-2022 entrants, small enterprises account for the majority of new firms (72.9%), while micro firms represent 15.1%, and large

or medium-sized firms comprise 12%. This distribution aligns with entry patterns typically observed under stable institutional conditions, where factors such as scale, capital availability, and formal organizational capacity influence market access.

In contrast, firms established after February 2022 exhibit a substantially different entry profile. More than half of post-2022 entrants (50.4%) begin as micro enterprises, 46% as small firms, and only 3.6% as medium or large entities.[7] This shift suggests that wartime production capacity primarily originated from the lower end of the size distribution. Entry was predominantly driven by small workshops, engineers, technical specialists, and volunteer-based initiatives that rapidly adapted existing skills and equipment to address urgent operational requirements. This pattern depicts the growth of productive capacity as a bottom-up process during crisis conditions. In wartime conditions, new entrants predominantly initiate their endeavors as microenterprises, consistent with wartime capital scarcity,

7 A Pearson chi-square test demonstrates that the distribution of entry sizes differs significantly between cohorts (X-squared = 208.49, df = 2, $p < 0.001$), indicating a clear structural shift toward micro-scale entry after the onset of the full-scale invasion.

heightened uncertainty, and necessity-driven entrepreneurship.

Hence, the findings reveal that, following the invasion, the entrepreneurial landscape experienced a sharp rise in micro-level entries and a more rapid progression to larger sizes. The wartime environment created a highly adaptable and opportunity-rich setting for UAV producers. Entry at the micro level required no capital investment; as a result, entrepreneurs could begin with simple tools, open-source designs, and skills gained from civilian IT or engineering backgrounds. This explains the increase in many micro-entities during the invasion.

Table 1 extends this comparison by analyzing post-entry size transitions (for methodological details, refer to Appendix B). Firms established after 2022 exhibit significantly higher upward size mobility than pre-2022 incumbents. Across all observed transitions, post-2022 firms upgrade at more than double the rate of earlier entrants (6.5% versus 2.9%).[8]

8 A chi-square test rejects the hypothesis of equal transition frequencies across cohorts ($X^2 = 19.032$, $df = 1$, $p < 0.001$), indicating consistently faster scaling among wartime entrants.

TABLE 1: Transition of firm size by entry cohort.

From size	To micro	To small	To medium/large
			Post-2022 entrants
Micro	80.0	19.5	0.5
Small	10.6	88.0	1.4
Medium/Large	3.4	11.4	85.3
			Pre-2022 incumbents
Micro	89.9	10.1	0.0
Small	9.4	89.3	1.3
Medium/Large	1.5	8.4	90.1

Focusing on firms entering at the micro level further substantiates this pattern. Among micro firms, post-2022 entrants upgrade to the small category at nearly twice the rate of pre-2022 micro incumbents (19.5% versus 10.1%).[9] These findings indicate that wartime entrants were not only more likely to begin as microfirms but also more likely to scale rapidly once operational relevance was established. In contrast, transitions from small to medium or large size remain infrequent for both cohorts (approximately 1.3%), highlighting ongoing constraints on capital deepening and large-scale investment during wartime.

The transition from micro to small appears to be driven by regenerative knowledge advantage (Brychko, M., & Braunerhjelm,

9 A statistically significant difference (X-squared = 11.989, df = 1, $p < 0.001$).

P., forthcoming) rather than by capital-driven forces. Firms that effectively integrated battlefield feedback, generated new insights, and enhanced existing knowledge stock were those that achieved scaling. Nonetheless, expanding beyond the small size requires greater fixed investments, more comprehensive production infrastructure, a stable supply chain, and the mitigation of wartime disruptions such as missile strikes, bombardments, and damage to infrastructure.

The innovation ecosystem decomposition

Ukraine's wartime UAV sector operates as a distributed, adaptive innovation system, shaped by the interactions among multiple institutional channels rather than by a single dominant set of incumbents. The system integrates firms of different sizes, state procurement and public authorities, frontline users, and civic and volunteer actors into an integrated production structure and flexible learning architecture that has evolved rapidly since 2022.

Structurally, the system is organized along a modular value chain comprising manufacturing (Tier 1 and 2), hardware components (Tier 3), software (Tier 4), research and development

(Tier 5), engineering services (Tier 6), and security-related activities (Tier 8). As shown in Figure 3, the balance across tiers shifted markedly over time.

During the baseline pre-war period, traditional aerospace manufacturing dominated the industrial landscape (49%), reflecting the legacy structure inherited from the Soviet industrial complex. Complementary functions, such as electronics, software, research and development, and engineering, were marginal in scope and played a relatively minor role. Innovation during this period was mostly found within vertically organized firms, with little collaboration between production, experimentation, and end users.

The hybrid war phase initiated a gradual rebalancing of this structure. As shown in Figure 3, the relative share of core manufacturing declined (from 49 to 40%), while software-related activities expanded (from 18 to 32%). This diversity reflects early efforts to adapt civilian technologies, particularly IT, communications, and sensing, to military applications. During this time, small engineering groups and IT startups explored reconnaissance and FPV technologies. However, these activities remained weakly integrated into formal procurement and defense manufacturing, receiving limited backing from the

government. The ecosystem at this stage showed signs of modularization and functional diversity to absorb shocks and reallocate resources during crises, but it lacked a fully developed coordination mechanism linking experimentation, production, and deployment.

Following the full-scale invasion in 2022, the internal composition of the ecosystem changed more decisively. Core manufacturing grew significantly (63%), but now operates within a much broader and more interconnected system. Hardware components, software development, and engineering services are consolidated into stable, complementary layers, while applied R&D and testing activities decreased slightly and were directly incorporated into production activities rather than functioning as separate institutional units. A defining characteristic of the wartime innovation system is the close integration between use environments and production units. This reflects more battlefield-oriented and use-driven innovation, where problem-solving under real-world conditions replaces lengthy pre-market testing and traditional R&D cycles.

Another notable feature of the post-2022 ecosystem is the rise of civic and volunteer organizations as structurally integrated

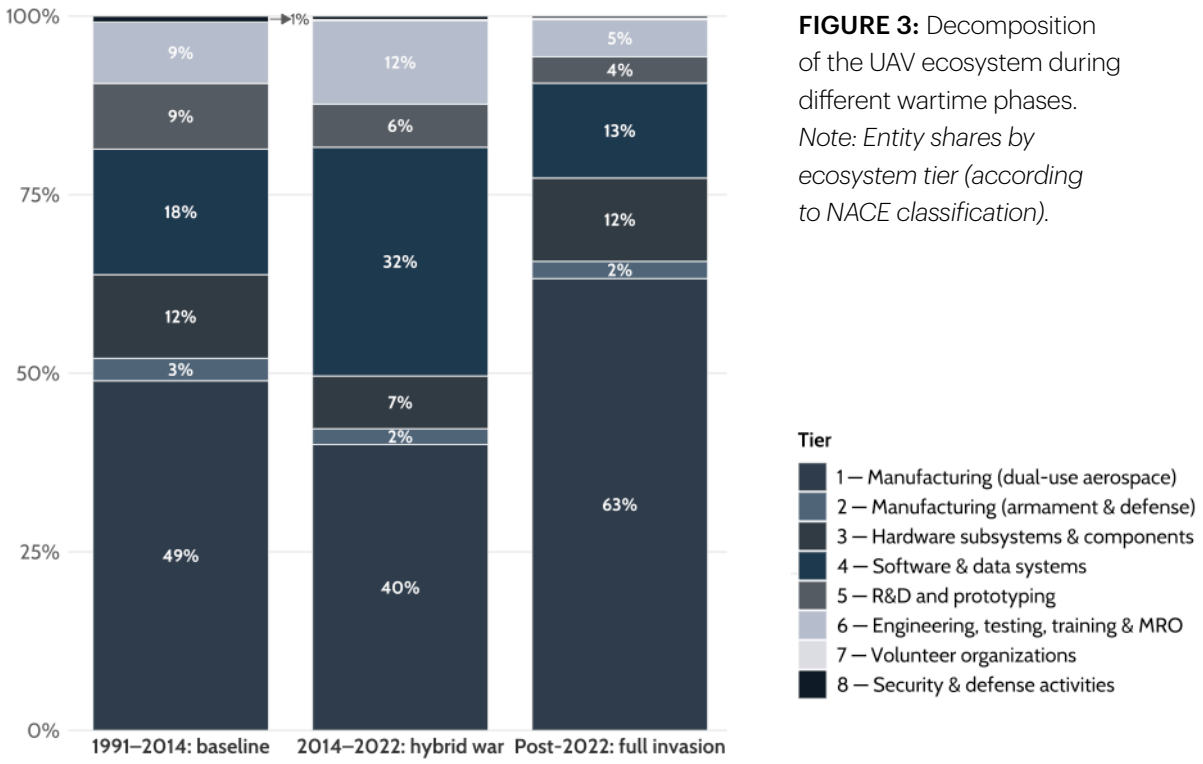


FIGURE 3: Decomposition of the UAV ecosystem during different wartime phases. *Note: Entity shares by ecosystem tier (according to NACE classification).*

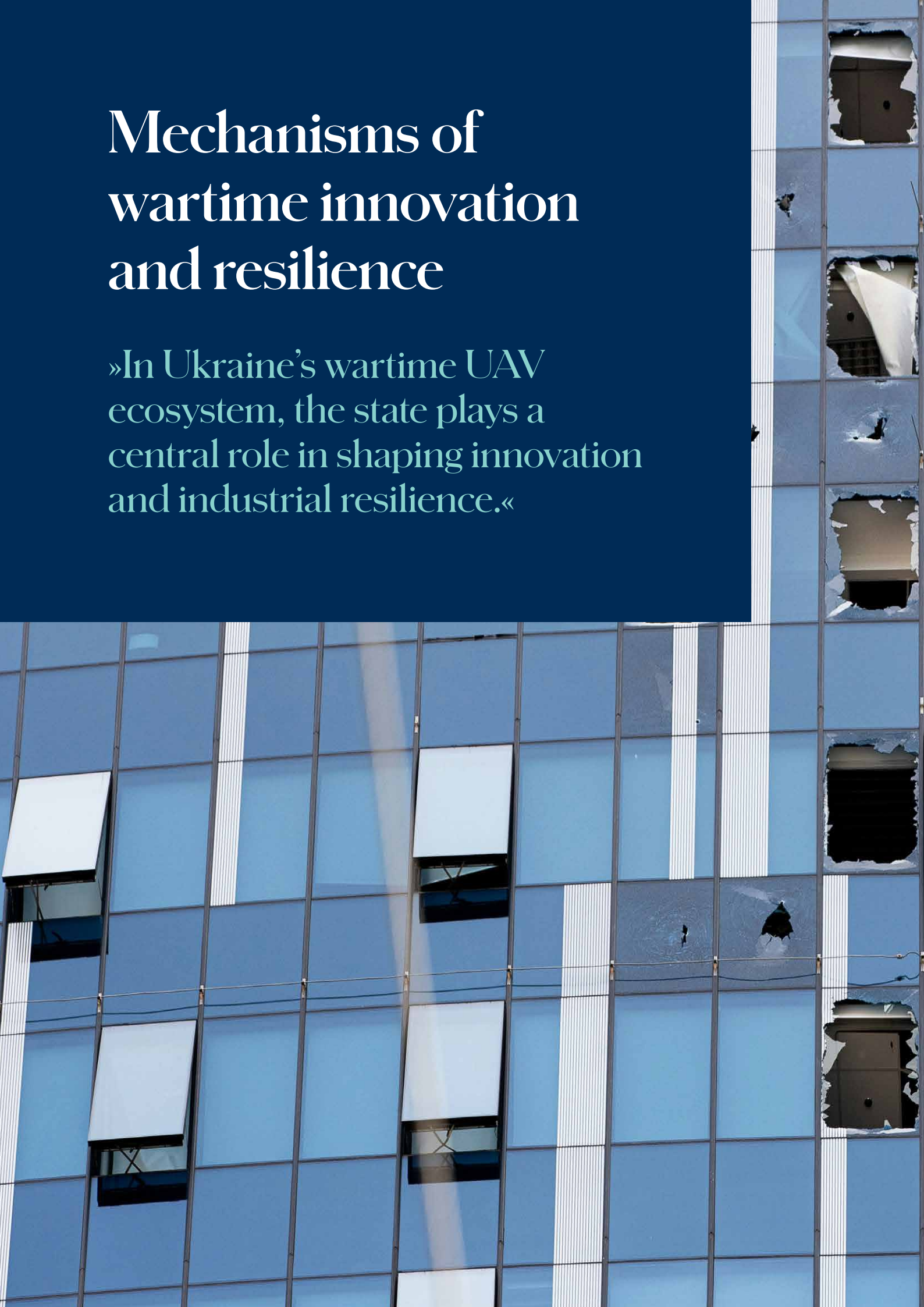
contributors to production and innovation. Although these groups make up a small share of the total entities (less than 1%), their functional significance is disproportionate. Volunteer workshops and non-profit initiatives translated frontline feedback into rapid design iteration, testing, and knowledge diffusion, effectively linking battlefield use environments with engineering and production capabilities.

Compared to other conflict- and post-conflict economies, Ukraine's wartime UAV industry restructuring stands out, as

these other economies typically see firm entry and innovation decline amid uncertainty, asset losses, and capital outflows (Miklian & Hoelscher, 2022b; Moritz et al., 2024; Naudé, 2007). Resilience was achieved through a distributed innovation system based on modularity, recombination, and rapid feedback loops. Innovation capacity is no longer resides primary within large incumbents but is distributed across interconnected layers that specialize in complementary tasks.

Mechanisms of wartime innovation and resilience

»In Ukraine's wartime UAV ecosystem, the state plays a central role in shaping innovation and industrial resilience.«



Policy interventions and state recognition mechanisms

Ukraine's wartime innovation system evolved under conditions of extreme urgency, uncertainty, and resource constraints. Rather than relying on a single instrument, resilience emerged through a combination of policy interventions, institutional adaptation, and informal coordination mechanisms that together enabled rapid experimentation, scaling, and learning.

The first major policy signal was the launch of the Army of Drones initiative in July 2022, jointly coordinated by the General Staff of the Armed Forces and the Ministry of Digital Transformation, with support from civic society and private donors.[10] Initially designed as a rapid mobilization effort to procure and deploy unmanned systems for frontline use,[11] the program quickly evolved into a broader coordination mechanism for pilot training, standardizing requirements, and supporting

10 United24, "Ukraine Raises an Army of Drones", 1 July 2022, https://u24.gov.ua/news/army_of_drones

11 The initial goal was to acquire 200 reconnaissance drones for the Armed Forces of Ukraine and to gather multi-use and commercial/hobby UAVs.

domestic producers. By aggregating military demand and signaling sustained state commitment to drone deployment, the Army of Drones reduced uncertainty for entrepreneurs and engineers considering entering the UAV production market. It functions as a goal-oriented demand instrument, validating drone manufacturing as a strategic priority during wartime.

Building on this initial mobilization, the government introduced formal regulatory reforms to adapt procurement procedures to wartime realities. In March 2023, the Cabinet of Ministers of Ukraine adopted Resolution No. 256, which established streamlined procedures for the procurement and commissioning of UAVs and enabled public procurement of electronic warfare (EW) devices.[12] The resolution reduced documentation requirements, shortened contracting timelines, and expanded eligibility for private suppliers, including small and newly established firms. By lowering procedural thresholds and administrative barriers, government intervention expanded access for firms with no prior procurement experience to enter formal state

12 The Cabinet of Ministers of Ukraine, 4 July 2024, https://www.kmu.gov.ua/en/news/udoskonaleno-protseduru-zakupivli-bezpilotnykh-system-vitchyznianoho-vyrobnytstva

demand channels and scale production more quickly. The procurement system for unmanned systems for the Armed Forces of Ukraine was further enhanced in May 2025 by launching a new three-tier drone procurement model: direct contracts, framework agreements, and the DOT-Chain Defense marketplace (managed by the Defense Procurement Agency (DPA)).[13] Regulatory adaptation continued with targeted efforts to ease operational and compliance constraints. In June 2025, the government adopted Regulation No. 282,[14] which eases flight requirements and maintenance procedures for UAVs. Most types of UAVs no longer need to be registered in the State Register of Civil Aircraft.

In parallel, the government introduced institutional platforms to coordinate innovation, validation, and deployment, notably the Brave 1 defense tech cluster. Established in April 2023, Brave 1 serves as a centralized interface for established

13 The Ministry of Defence of Ukraine, 25 May 2025, https://mod.gov.ua/en/news/the-ministry-of-defence-s-defence-procurement-agency-dpa-introduces-a-new-procurement-model-for-unmanned-systems

14 The Ministry of Defence of Ukraine, 17 July 2025, https://mod.gov.ua/en/news/ministry-of-defence-simplifies-regulations-for-using-ua-vs

manufacturers (with established R&D or production), startups, defense-tech developers and engineers, military units, public agencies, and other stakeholders in the defense tech industry. The platform provides structured support across the innovation pipeline, including battlefield testing, validation, and codification of new experimental technologies; regulatory and legal guidance; and grant financing for early-stage defense innovations that meet the operational needs of Ukraine's Security and Defense Forces. To further shorten the transition from experimentation to deployment, the government introduced the Brave1 Market[15] in April 2025 as a complementary procurement channel for innovative and experimental technologies. Unlike other digital weapons marketplaces (such as DOT-Chain Defense), Brave1 Market is designed to enable rapid access to cutting-edge solutions with unique capabilities for military units, including systems that may precede full formal codification. Military units can procure technologies using direct monthly allocations or combat-earned "e-points"

15 Digital State UA, "Ukraine Launches Brave1 Market for Defense Innovation", 28 April 2025, https://digitalstate.gov.ua/news/tech/brave1-market-ukrayina-zapuskaye-marketpleys-viyskovykh-innovatsiy

(introduced in July 2025),[16] which soldiers earn for destroying Russian targets, thereby linking effectiveness with demand-driven adoption.

A second pillar of Ukraine's wartime procurement architecture is DOT-Chain Defense,[17] a digital marketplace operated by the DPA under the oversight of the Ministry of Defense. Unlike decentralized brigade-level purchasing, DOT-Chain Defense relies on centrally managed DPA budgets. DOT-Chain Defense embodies the Ministry of Defense's procurement philosophy, emphasizing centralized quality control, standardized specifications, verified suppliers, and predictable logistics. The DPA maintains framework contracts, manages supplier relationships, coordinates delivery, and ensures accountability and auditability across transactions. DOT-Chain Defense is designed to scale proven, codified solutions across the armed forces. Together, the two platforms reflect a dual procurement logic that

16 Dev, 29 January 2026, Ukrainian military has already received 240,000 drones for e-points on Brave1 Market, https://dev.ua/en/news/240-000-droniv-za-ie-baly-1769682437

17 The Ministry of Defence of Ukraine, 7 July 2025, https://mod.gov.ua/en/news/ukraine-launches-dot-chain-defence-a-digital-system-for-rapid-delivery-of-weapons

emerged under wartime conditions: centralized procurement to ensure reliability and scale (covered by OT-Chain Defense), alongside experimental channels to sustain rapid innovation and adaptation (enabled by Brave1 Market).

A key organizational milestone was the establishment of the Unmanned Systems Forces[18] as a separate branch of the Armed Forces of Ukraine in February 2024. This reform institutionalized UAV operations within the military command structure, clarifying responsibility for doctrine development, training, operational use and feedback collection. By formalizing drones as a distinct capacity rather than an auxiliary tool, the reform strengthened demand articulation and created a stable interface between frontline users and producers.

In parallel with procurement and coordination reforms, Ukraine introduced Defense City[19] as a targeted regulatory and

18 The Armed Forces of Ukraine's Unmanned Systems Forces, https://usforces.army/en/

19 Digital State UA, "Ukraine Launches Defence City: A New Special Regime for Scaling Defense Production", 5 January 2026, https://digitalstate.gov.ua/news/tech/ukraine-launches-defence-city-a-new-special-regime-for-scaling-defense-production

economic framework to support the scaling of domestic defense manufacturing. Defense City Resident status offers benefits such as tax incentives (exemptions from land, property, and environmental taxes), easier customs procedures for importing equipment and components, protections for information security, and government-backed support for relocating or physically protecting production facilities if security conditions demand it. Furthermore, the National Bank of Ukraine announced a partial relaxation of currency controls concerning certain types of cross-border transactions. By reducing regulatory friction and improving investment predictability, the government encourages long-term capital commitments.

Complementing previously mentioned initiatives, the Ukrainian government is also investing in information and coordination infrastructure to reduce administrative bottlenecks and improve feedback between the military, producers, and government authorities. The Ministry of Defense launched an online Deregulation portal,[20] enabling military units, firms, engineers, and civilians to submit proposals to streamline defense-related

20 Deregulation within Ukraine's Ministry of Defense, https://deregulation.mod.gov.ua/

procedures and eliminate unnecessary constraints. Additionally, the Ministry of Defense introduced unified digital platforms, Zbroya Smart Force[21] and Partner MOD,[22] for defense manufacturers and service providers. Zbroya Smart Force platform functions as an integrated access point that consolidates services previously dispersed across multiple initiatives and agencies. It provides centralized access to regulatory guidance (including procedures for obtaining critical enterprise status and reserving defense-sector employees), codification of armament and military equipment samples, and structured educational resources for defense producers. In addition, it aggregates information on preferential lending instruments for defense-industry teams, testing opportunities, and matchmaking between system integrators and component suppliers. By integrating services offered through Diia,[23] Brave1, and other

21 Portal of public services and opportunities for weapons manufacturers in Ukraine "Zbroya Smart Force", https://www.zbroya.gov.ua/en/services

22 Portal for proposals on developments, materials, and processing methods from potential manufacturers or suppliers "Partner MOD", https://partner.mod.gov.ua/en

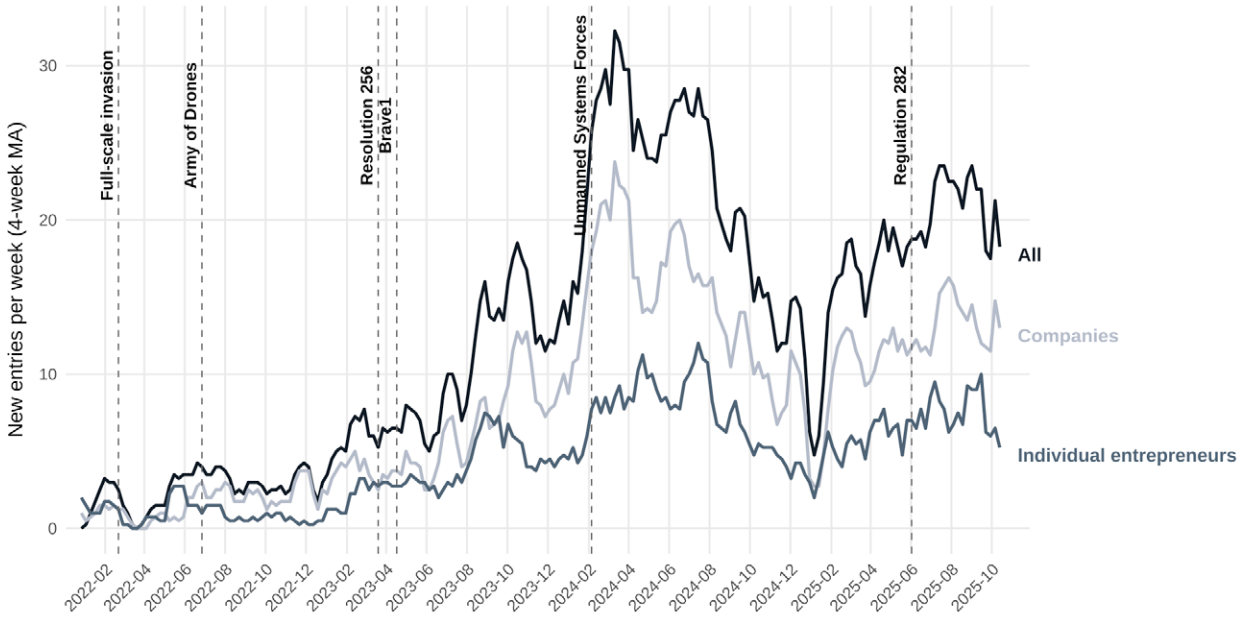
23 Diia ("Digital State") is a Ukrainian government digital platform and ecosystem of e-services designed to provide citizens and businesses with online access to public administration services, including business registration, licensing, permits, and other interactions with the state (see https://expo.diia.gov.ua/)

defense-industry initiatives, it significantly reduces administrative and coordination burdens, especially for small and newly established firms. In doing so, the platform lowers non-financial barriers to entry and accelerates the transition from experimentation to scaled production under wartime conditions.

Taken together, these governmental interventions reoriented Ukraine's wartime industrial organization toward a more adaptive system centered on rapid entry and iterative validation. The overall result was not solely accelerated innovation but also a transformation of entrepreneurial dynamics, enabling small firms, new entrants, and non-traditional producers to participate in the defense innovation system, while the state continued to maintain coordination. These interventions effectively dismantled the bureaucratic layers that, in peacetime, would have delayed or discouraged entrepreneurial entry, thereby substantially altering the mechanisms through which knowledge moved from experimentation to deployment.

Regulatory requirements, organizational inertia, certification procedures, procurement rules, and inherent uncertainty in innovative ideas, among others, often constrain innovation, slowing or preventing the commercialization of new ideas, a

FIGURE 4: Weekly entry into Ukraine's drone ecosystem in the context of major government initiatives and events (2021–2025).



phenomenon the literature explains as a knowledge filter (Acs et al., 2009; 2013; Alvarez & Barney, 2005, 2007; Audretsch & Keilbach, 2007). A large body of empirical research shows that even substantial investments in R&D may fail to translate into productive outcomes and economic growth when such filters remain binding (Carlsson et al., 2007; Braunerhjelm et al., 2010). Ukraine's wartime policy response intentionally eased numer-

ous of these constraints that fundamentally alter the knowledge filter. This significantly reduced the time and institutional gap between knowledge creation and operational use.

As regulatory and administrative barriers were rapidly relaxed, the conventional institutional constraints that typically slow the commercialization of new technologies became less binding. Importantly, the removal of formal barriers did not eliminate selection pressures (the knowledge filter) but transformed their nature. Recent research highlights that the knowledge filter is not fixed but varies across institutional and situational contexts (Audretsch et al., 2025). Under wartime conditions, rather than being screened primarily through administrative compliance, organizational seniority, or innovators' personal characteristics, technologies were increasingly evaluated through performance in real operational battlefield environments. Frontline use under electronic warfare, adverse weather, and active countermeasures, as well as immediate combat feedback, performed a filtering function: only technologies that demonstrated operational effectiveness progressed towards scaling, formal procurement, and the wider diffusion of effective technologies across the defense ecosystem. This extends the

knowledge spillover perspective to settings where commercialization is governed less by institutional inertia and more by real-time performance under extreme conditions (Brychko, M., & Braunerhjelm, P., forthcoming).

Entry dynamics and policy signals

Figure 4 shows how entry into Ukraine's UAV production evolved over time, displaying weekly registrations of new producers from 2021 to 2025, and highlights key military and policy milestones that influenced the sector's growth.

Before the full-scale invasion, entry into the UAV ecosystem was restricted. Demand for unmanned systems was limited, and existing regulatory frameworks constrained broader civilian and dual-use production while also serving as a "knowledge filter" at the time.

The full-scale invasion beginning in February 2022 initially disrupted economic activity. The formation of new firms slowed sharply, and for several months, there were few new entrants in the UAV sector. As the initial shock eased, new entries gradually increased, albeit at a slow rate. Wartime uncertainty, emergen-

cy mobilization, and infrastructure disruptions limited the capacity of new producers to establish and expand.

A more sustained increase in entry began in mid-2022. The launch of the Army of Drones initiative coincided with a steady rise in the number of new producers, particularly among individual entrepreneurs. This phase reflects early wartime adaptation, characterized by decentralized experimentation and rapid response to frontline needs. A more pronounced increase in entry occurred in early 2023 following the adoption of Resolution No. 256 and the establishment of Brave1. The initiatives provided greater regulatory clarity, simplified procurement mechanisms, and institutional support for defense-related innovation. Entry expanded among both companies and individual entrepreneurs, indicating improved conditions for prototyping, niche manufacturing, and integration into the defense ecosystem. Entry reached its highest level after the establishment of the Unmanned Systems Forces as a separate branch of the Armed Forces in early 2024, signaling the long-term importance of Unmanned Systems in military doctrine. From late 2024 through early 2025, entry declined as technical standards tightened and the sector consolidated. A further increase in

entry occurred in mid-2025 following the introduction of Regulation No. 282, which eased flight and maintenance requirements for certain UAV types.

Procurement access, participation and concentration

In Ukraine's wartime UAV ecosystem, the state plays a central role in shaping innovation and industrial resilience. State recognition refers to the formal interactions through which the state acknowledges and engages companies, individual entrepreneurs, and other ecosystem participants as contributors to prioritized wartime objectives. In this report, state recognition is measured by firms' entry into institutionalized state engagement channels recorded in public finance and procurement data. These three channels differ in depth and commitment.

First, public procurement is used to identify both access and initial recognition by distinguishing entities that submitted at least one tender bid during 2023–2025 and those that secured (won) at least one contract.

Second, deeper financial involvement is captured through an indicator for public funding received. Recipients of public

funds are entities that obtain public resources through procurement contracts, grants, or subsidies, regardless of the payment channel (e.g., through the Ministry of Defense or the Ministry of Digital Transformation).

Third, the highest level of engagement is measured by the amount of public funds managed. Managers of public funds, as identified in Treasury execution data, are entities that receive payments directly from the Treasury and are recorded as executing budget expenditures. These entities do not possess legal authority as budget holders or spending units, nor do they allocate funds or oversee procurement; rather, they act as direct payees executing contractually specified spending.

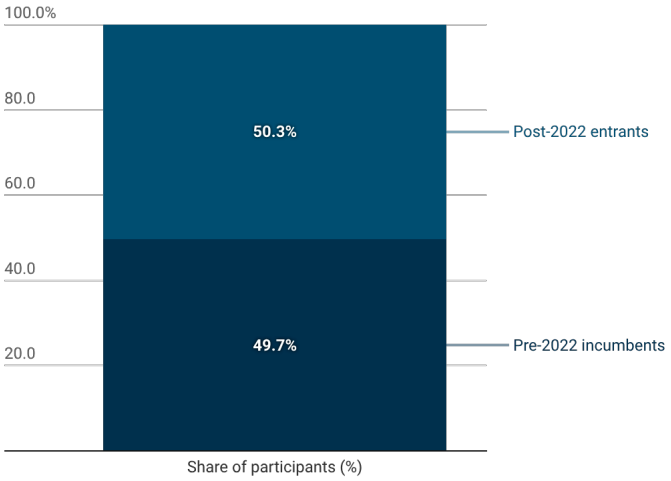
This classification reflects the modality of budget execution, not discretionary authority over public spending, as private firms do not allocate procurement budgets or supervise public funds. For example, a drone producer receiving an innovation grant under the Brave1 program is classified as a recipient only, while a drone manufacturer paid directly by the Treasury under an emergency procurement or framework contract is classified as a manager. Although such managers may rely on subcontractors for components or assembly, subcontracting occurs

through private commercial contracts; public budget execution ends at the direct Treasury payee, and downstream payments do not constitute public fund management.

One of the clearest ways in which the state signals priorities and recognizes capable producers is through public procurement. Public procurement connects operational military needs with domestic technological capabilities and provides firms with funding, validation, and a pathway to scale. In March 2023, the Ukrainian government adopted Resolution No. 256, which introduced simplified, direct procurement procedures for domestically produced UAVs and electronic warfare equipment for the defense forces. The reform aimed to reduce procedural delays, accelerate contracting, and better accommodate wartime production realities, including the presence of small, rapidly adapting suppliers and newly established producers.

Figure 5 shows the decomposition of entities participating in public procurement during 2023–2025. In absolute terms, procurement participants are almost evenly split between the two groups (419 pre-war incumbents and 424 post-2022 entrants), corresponding to 49.7% incumbents and 50.3% war-

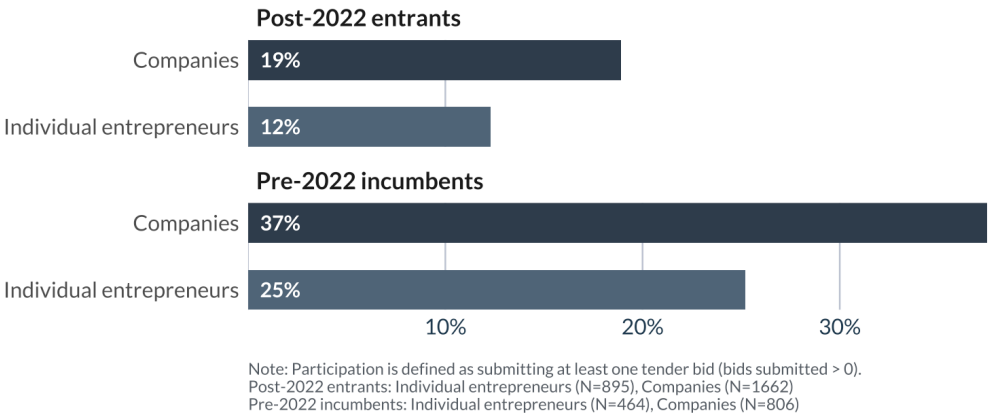
FIGURE 5: Decomposition of entities participating in public procurement during 2023–2025.



time entrants. This near parity in aggregate numbers indicates that wartime public procurement incorporated a substantial number of newly established producers, instead of remaining restricted to pre-war suppliers. At the same time, this composition should be interpreted in light of the much larger overall population of wartime entrants.

Figure 6, therefore, shifts the focus from absolute counts of participation to participation rates, showing the share of UAV producers who submitted at least one tender bid during 2023–2025. The figure distinguishes between entities that entered the sector after 2022 (new post-2022 entrants) and those that were active before full-scale invasion (pre-2022 incumbents), as well as between organizational forms (companies and individual entrepreneurs).

FIGURE 6: Participation in public procurement.



Note: Participation is defined as submitting at least one tender bid (bids submitted > 0).
Post-2022 entrants: Individual entrepreneurs (N=895), Companies (N=1662)
Pre-2022 incumbents: Individual entrepreneurs (N=464), Companies (N=806)

While the introduction of simplified procedures lowered formal and procedural barriers to participation, the data indicate that this reform did not automatically translate into broad-based engagement with public procurement by wartime entrants or individual entrepreneurs. While the range of legally available procurement mechanisms expanded, effective participation continued to depend on firms' administrative capacity, ability to meet documentation requirements, demonstrate reliability, and delivery capacity.

The results of Figure 6 support that both pre-2022 incumbents and post-2022 entrants participated in tenders, suggesting that the system remained open to new actors during the war. How-

ever, participation is uneven across groups. Among companies that were established before full-scale invasion, 37% submitted at least one tender bid, compared to only 19% of companies that entered UAVs production during the war. A similar pattern is observed among individual entrepreneurs, where participation falls from 25% among incumbents to 12% among wartime entrants. This finding indicates that rapid expansion in the number of UAV producers after full-scale innovation did not translate into a proportional increase in procurement participation.

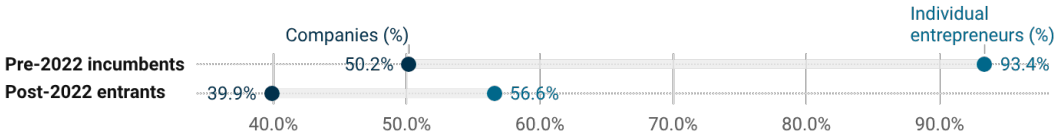
From a resilience perspective, this highlights a central tension in the wartime innovation system. Ukraine's UAV ecosystem proved highly adaptive in generating new production capacity in response to urgent battlefield needs. However, procurement institutions adjusted more slowly than innovation dynamics, limiting the speed at which new capabilities could be formally scaled through state demand. This helps explain why much early wartime innovation diffused through informal channels, such as direct collaboration between military and industry and volunteer networks, before, if at all, transitioning to formal procurement.

The Ukrainian experience underscores that industrial resilience in crisis depends not only on stimulating entry and innovation, but also on ensuring that the procurement system can rapidly absorb and integrate new producers. Otherwise, the benefits of rapid entry risk remain underutilized at the level where state demand is most concentrated.

Figure 7 shifts the focus from access to outcomes, examining aggregate success conditional on bidding, abstracting from differences in the number of participating entities.

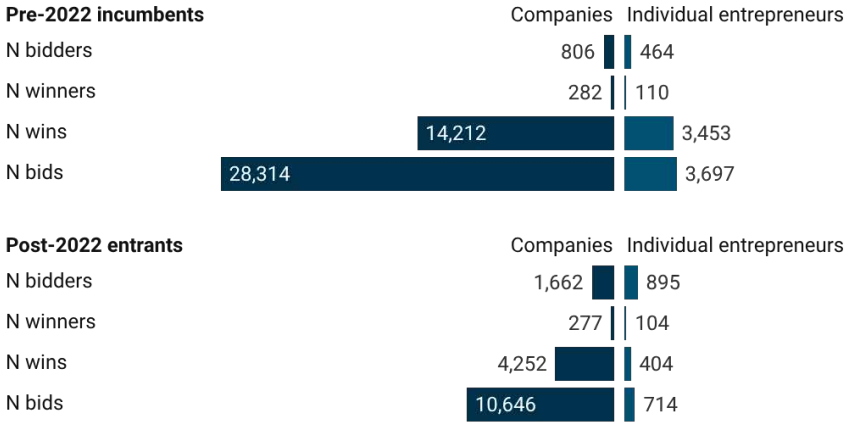
Figure 7 illustrates apparent differences in aggregate success among different cohorts and organizational structures. Among companies, pre-2022 incumbents achieve a higher aggregate win rate (50.2%) than post-2022 entrants (39.9%), indicating that incumbents are not only more likely to participate in procurement but also more effective when they do. This pattern aligns with incumbents' greater experience with procurement procedures, existing production capacity, and reputational capital. Individual entrepreneurs display markedly higher aggregate win rates in both cohorts (93.4% among incumbents and 56.6% among wartime entrants). However, these high rates should be interpreted with caution. As shown

FIGURE 7: Aggregate win rates in public procurement.



Note: Aggregate win rate calculated as the total number of tenders won divided by the total number of bids submitted within each group.

FIGURE 8: Procurement participation and outcomes by entry cohort and organizational form.



Notes: N bidders = entities submitting ≥1 bid; N winners = entities winning ≥1 tender; N wins = total tenders won; N bids = total bids submitted. Panels separate pre-2022 incumbents from post-2022 entrants.

in Figure 6, individual entrepreneurs participated in procurement at much lower rates, and as Figure 8 later demonstrates, they typically submit a small number of bids. High aggregate win rates among individual entrepreneurs, therefore, reflect selective and targeted participation rather than broad-based competitiveness across procurement markets.

Aggregate win rates, however, do not show how procurement outcomes are distributed among successful entities. Figure 9 compares median and mean numbers of tenders won among entities that secured at least one contract. Across all groups, mean values substantially exceed the medians, indicating pronounced concentration in procurement outcomes, particularly among incumbent companies. While the median incumbent company wins eight tenders, the mean exceeds fifty, implying that a small subset of firms captures a disproportionate share of contracts.

Individual entrepreneurs also exhibit skewed outcomes, but at a smaller scale. Among incumbents, the median number of tenders won is 4, whereas the mean exceeds 30. Post-2022 entrants display a lower absolute level of success, but divergence between mean and median remains evident, indicating that repeated procurement success is already emerging among a limited subset of new entrants. These patterns demonstrate that public procurement outcomes are highly concentrated, particularly among incumbent entities.

Figure 10 examines the mechanisms underlying this concentration by comparing average bidding activity and average wins among

FIGURE 9: Concentration of procurement outcomes.

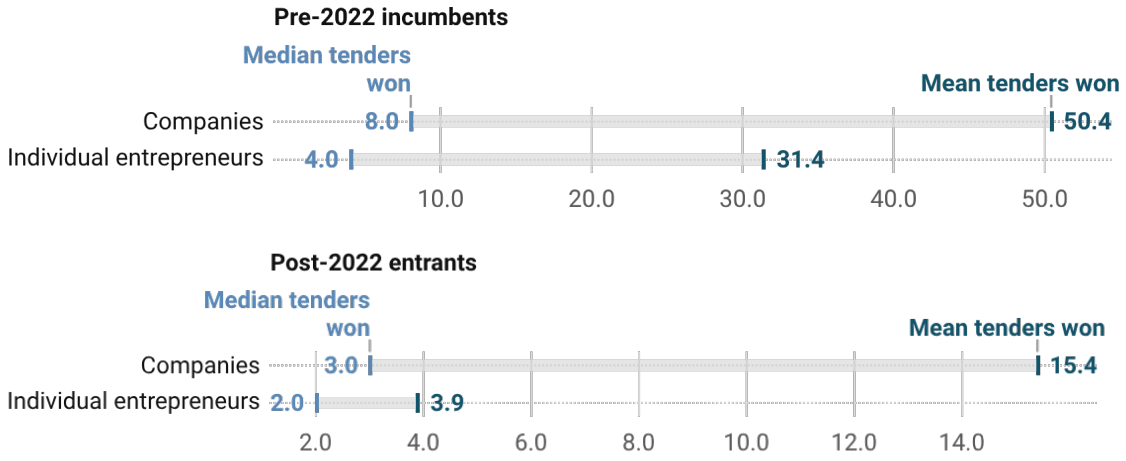
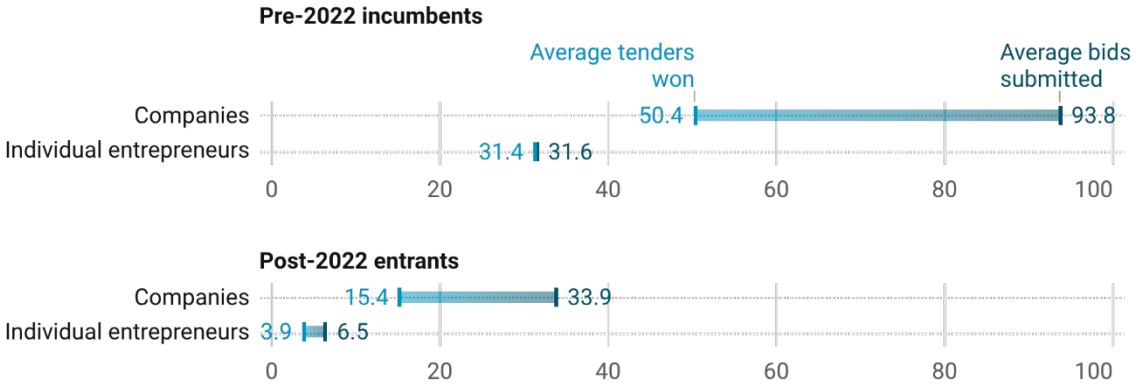


FIGURE 10: Scale and bidding behavior among successful entities.



entities that submitted at least one bid. Incumbent companies operate at a substantially larger scale, submitting an average of 93.8 bids and securing more than 50 contracts. Wartime entrant companies participate on a smaller, but still considerable scale.

In contrast, individual entrepreneurs submit significantly fewer bids, especially wartime entrants, and their average number

of wins closely follows their bidding activity. This suggests selective participation in tenders in which success is more likely. Consequently, high win rates among individual entrepreneurs do not lead to large procurement volumes.

Wartime government recognition

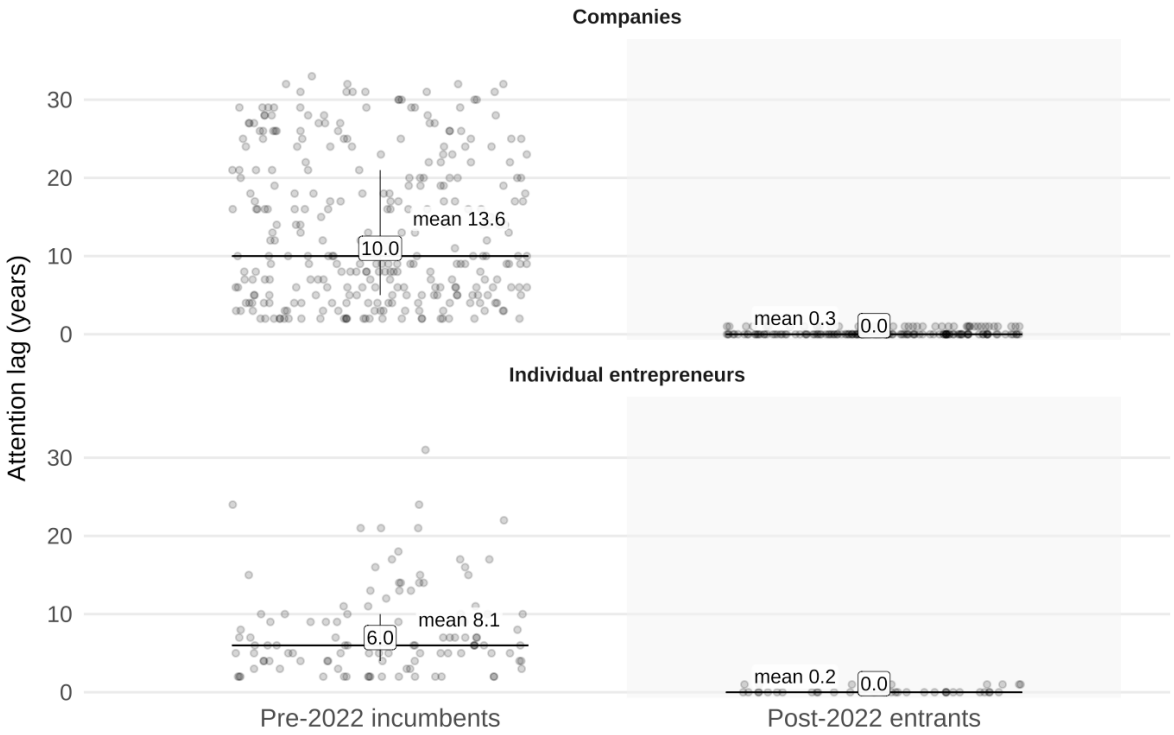
Under conditions of urgent military demand, the Ukrainian government dramatically shortened the time between firm entry into the industry and formal recognition[24] (for methodological details, refer to Appendix B), integrating new producers into procurement and funding channels at an unusually early stage of their life cycle. Figure 11 shows how quickly different types of entities attracted wartime state attention, measured as the lag between registration and the first observed tender win or recipient/management of public funds during 2023–2025.

24 The first instance, in which a firm enters a formal state engagement channel, recorded in public finance or procurement data, measured by a public procurement tender win or by appearing as a Public Funding Recipient or direct Treasury payee executing budget expenditures (Public Funding Manager), rather than exercising authority over public funds.

Pre-2022 incumbents show long, highly dispersed selection lags. Among incumbent companies that receive wartime state recognition, the median lag from entry is approximately 10 years, with an average of 13.6 years, indicating significant variation across firms. In contrast, individual entrepreneurs exhibit shorter but still extended timelines, typically having been active for approximately 6 years before receiving comparable wartime recognition. The length of these lags suggests that many incumbents probably entered the sector near or just after Ukraine's initial invasion in 2014.

Post-2022 entrants are recognized almost immediately within the wartime period, i.e., the median attention lag is zero years for both companies and individual entrepreneurs. Mean attention lags are also very short (0.3 years for companies and 0.2 years for individual entrepreneurs), showing that recognition generally followed entry within a few months. This is a logical pattern, indicating that, within the wartime observation window, newly established firms were integrated into procurement and funding channels at an earlier stage of their life cycle. Because the data capture recognition events only during the wartime period, these results

FIGURE 11: Wartime recognition timing by entry cohort.



Notes: Each dot represents an individual firm. Horizontal bars denote the median attention lag (with numeric labels). Thin vertical lines indicate the interquartile range (IQR). Mean attention lag is shown as a small offset label.

FIGURE 12: Concentration (overlap) of the state recognition.

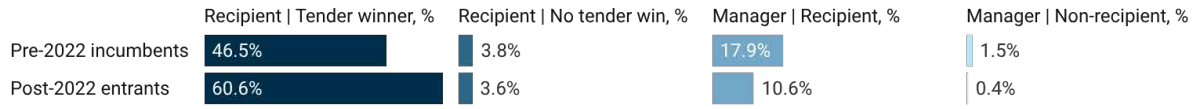
Notes: Managers = entities managing public funds; Recipients = entities receiving public funding.

describe differences across cohorts rather than a direct comparison between wartime and peacetime recognition regimes.

Companies interact with the state during wartime through multiple recognition channels simultaneously (see Figure 12), including managing public funds, receiving public funding and winning procurement tenders. According to YC.Market records, individual entrepreneurs are largely absent from categories of public-fund recipients and fund managers, which are observed almost exclusively among legal entities. The results indicate a significant overlap across these roles for both pre-2022 incumbent and post-2022 entrant companies.

Among pre-2022 incumbents, overlap is particularly strong. Nearly 90% of entities managing public funds after 2023 are also wartime tender winners, and 87% of wartime funding recipients also win tenders. This suggests that, for established firms, different forms of state recognition tend to accumulate rather than operate independently. For post-2022 entrants, overlap remains substantial but is more uneven across channels. A large share of wartime managers of public funds are also funding recipients (79%), indicating that newly established firms entrusted with administrative roles often also receive direct financial support. At the same time, overlap between management roles and tender wins is lower (72%), suggesting that procurement success among entrants is somehow more

FIGURE 13: Wartime recognition timing by entry cohort.



selective. The evidence points to a nested overlap across recognition channels.

Figure 13 examines whether deeper forms of wartime state engagement arise conditionally on prior recognition rather than being allocated independently. The figure reports four conditional probabilities, separately for pre-2022 incumbents and post-2022 entrants.

First, the likelihood of receiving public funding is dramatically higher among tender winners than among non-winners. Among pre-2022 incumbents, 46.5% of companies that won at least one tender subsequently received public funding, compared to only 3.8% of companies that never won a tender. The difference is even more pronounced for wartime entrants: 60.6% of tender winners received public funding, versus just 3.6% of non-winners. This sharp divergence indicates that procurement success acts as a key gateway to deeper state engagement.

Second, conditional escalation is also evident at the higher levels of the recognition hierarchy. Among funding recipients, a significant portion went on to assume coordination roles as public funding managers. Among pre-2022 incumbents, 17.9% of recipients became managers, compared with only 1.5% of non-recipients. Wartime entrants exhibit the same ordering, albeit at lower levels: 10.6% of recipients became managers, compared with 0.4% of non-recipients.

Taken together, these patterns demonstrate that wartime state recognition follows an ordered, stepwise progression, in which deeper roles become substantially more likely to occur after firms' earlier stages. The nestedness observed across recognition channels indicates that firms acting as public funding recipients or managers are rarely observed among firms outside this procurement base. In this context, the term procurement base refers to firms that have won at least one wartime public procurement tender. Figure 13 adds a dynamic perspective by showing that firms that win procurement tenders are far more likely to move on to receive public funding and, in some cases, to assume fund-management roles. These findings suggest that wartime state recognition operates less as a flat set of independent opportunities and more as a ladder of engagement,

TABLE 2: Intensity of public funding-based state recognition.

Recognition layer	Entry cohort	N	Mean transactions	Median transactions	Mean amount	Median amount
Recipient	Pre-2022 incumbents	151	28.8	4	24,296,324	981,790
	Post-2022 entrants	218	7.5	2	10,785,298	1,976,750
Manager	Pre-2022 incumbents	37	82.3	5	85,815,705	4,079,070
	Post-2022 entrants	29	24.6	3	26,686,431	2,528,124

Notes: Recipient (R=1) indicates entities receiving public funding; Manager (M=1) indicates entities managing public funds on behalf of the state. Statistics are calculated conditional on participation in each recognition layer. Amounts are reported in nominal currency units.

where earlier recognition increases the likelihood of deeper involvement.

Table 2 compares the intensity of funding-based stated recognition once access is granted. It shows that public funding during wartime is not only selective in access but also highly unequal in intensity. Among funding recipients, wartime entrants are clearly incorporated into the system; they are more numerous than pre-2022 incumbents (218 vs 151 companies). However, incumbents receive substantially more intensive support. Conditional on receiving funding, pre-2022 incumbents average nearly four times as many transactions as wartime entrants (28.8 vs 7.5 transactions) and receive more than twice the average funding amount (24.3 vs 10.8 million UAH). This gap widens sharply at the managerial layer. While wartime entrants do obtain manager roles, incumbents manage more than three

times as many transactions on average (82.3 vs 24.6) and oversee more than three times the total funding volume (85.8 vs 26.7 million UAH).

Ukraine's wartime innovation systems demonstrate a dual logic of inclusion and control. While procurement and funding mechanisms were rapidly opened to new wartime entrants, the state continued rely on pre-war incumbents for the most responsibility-intensive roles, particularly management of public funds. The recognition ladder thus combines rapid entry with conservative delegation at its upper tiers.

Knowledge bases, use environments, and capability recombination

One of the central drivers of wartime innovation was a shift in where and how relevant knowledge was produced. In contrast to peacetime innovation systems, where the knowledge base and creation are typically concentrated within incumbent firms, research organizations, and formal R&D structures (Acs et al., 2004; Audretsch et al., 2006), wartime settings relocate knowledge generation to use environments. Operational units, combat-experienced personnel, including veterans, volunteer

engineers, and informal technical communities, have become key producers and validators of new knowledge and entrepreneurial opportunities, rather than passive recipients of spillovers from incumbents.

In less ideal environments, incumbents can become slow and strategically constrained. In line with the concept of "lead users" (Von Hippel, 1986), frontline brigades became the primary source of knowledge because of their knowledge about battlefield needs for technological solutions and experimental insights. These actors actively develop, test, and refine solutions in combat settings, which then diffuse to entrepreneurs and small producers through both formal and informal channels. This implies that the battlefield functions as an epistemic institution (Miller, 2022), which, by generating, authenticating, and distributing knowledge in real time, complements and, in certain instances, replaces conventional industrial research and development frameworks.

One of the clear illustrations of the origin of new epistemic institutions is the rapid emergence of fiber-optic-tethered FPV drones in Ukraine. In contrast to traditional radio-controlled systems, these drones use physical connections to the operator

via fiber-optic cables, making them largely resilient to electronic jamming and effective in complex terrain such as forests or heavily contested electromagnetic environments (Carlstedt & Lyth, 2025). Following the first battlefield use of such systems by Russian forces, Ukrainian frontline units and volunteer workshops quickly observed their operational advantages, reverse-engineered key components, and began producing domestic variants, including locally wound fiber-optic cables. This process translated directly into entrepreneurial activity. One illustrative case is 3DTech,[25] founded in 2023 by a former Azov Regiment fighter after recovering from combat injuries. The firm's initial FPV model ("Predator") was explicitly shaped by frontline experience, incorporating design features informed by observed performance under jamming and combat conditions. The case demonstrates how operational knowledge generated in combat settings can be rapidly codified into new firms and production capabilities. Rather than emerging through delayed spillovers from incumbent R&D, innovation arose through the

25 3DTech is a Ukrainian manufacturer of next-generation combat FPV drones, specializing in fiber-optic control systems, electronic warfare (EW) protection, https://www.3dtech.com.ua/en/about

immediate conversion of battlefield experience into organizational and technological development, highlighting the role of frontline actors as central epistemic institutions in wartime innovation systems.

Use-based experimentation generates actionable knowledge on performance, failure modes, and design trade-offs much faster than traditional R&D cycles. As a result, knowledge creation, validation, and dissemination became closely integrated, with operational feedback directly influencing future design and production choices. This shift was supported by the development of institutionalized testing and validation environments that incorporated real-world use directly into the innovation process, making them accessible to both domestic and international manufacturers. Domestic manufacturers gained access to structured testing through the Ministry of Defense's mil-tech platform "Poligon",[26] which allows companies to run trials either at their own facilities or at accredited military testing bases (State Scientific Research Institute of Armament and Military Equipment Testing and

26 Testing applications portal "Poligon", https://poligon.zsu.gov.ua/how-it-works

Certification[27]). Simultaneously, the "Test in Ukraine"[28] initiative applied this use-environment approach to international producers, enabling foreign companies to evaluate experimental systems under active combat conditions. Manufacturers can use two testing scenarios: test on-site with the company's representatives ("Test together"), making rapid real-time adjustments, or delegate testing to Brave1 ("Leave it to us"), with troops conducting trials and providing a comprehensive report.

The wartime setting also transformed how knowledge is circulated. In peacetime, knowledge spread through patents, publications, organized R&D collaborations (intentional spillovers), as well as labor mobility, reverse engineering, and informal communication (unintentional spillovers) (Kraft & Rammer, 2023). In Ukraine, particularly at the beginning of the full-scale invasion, firmware adjustments and design blueprints were openly discussed on Telegram forums and groups. These

27 State Scientific Research Institute of Armament and Military Equipment Testing and Certification was established in October 2017, https://dndivsovt.mil.gov.ua/en/about-the-institute/

28 "Testing in Ukraine" official portal, https://portal.usf.com.ua/submit-your-solution

channels, unlike traditional scientific journals or industry trade fairs, operate almost in real time, matching the pace of combat adaptation. Simultaneously, captured russian systems, including drones, are reverse engineered, and with the rotation of personnel across military units and frontline battlefields, facilitate the diffusion of experience-based knowledge. This pattern is consistent with the broader entrepreneurship literature, which emphasizes the role of tacit knowledge in knowledge diffusion (Braunerhjelm et al., 2020).

Traditional innovation frameworks also assume that knowledge accumulation precedes application. This means that firms invest in R&D, and knowledge is stored within organizations, then later spreads through entrepreneurial activity or commercialization (Acs et al., 2004; Qian & Acs, 2013). In such models, the primary analytical focus is on how efficiently existing knowledge stocks are mobilized and transferred, while use is treated as an endpoint (Helfat & Peteraf, 2009; Nielsen, 2006; Teece, 2007; Teece et al., 1997) rather than a source of further learning. Even recent extensions, such as knowledge-based dynamic capabilities, largely retain the assumption that knowledge remains a relatively stable repository managed through sequential stages (Robertson et al., 2023).

The wartime conditions challenge this stock-based logic. In highly turbulent environments, innovation emerged through continuous interaction between use and redesign, with front-line deployment acting as a central mechanism of knowledge creation (producing new insights) rather than mere validation (consumption of existing knowledge). In particular, each dones combat deployment (successful or failed) generates immediate feedback on system performance, vulnerabilities, and countermeasures. This operational feedback circulated quickly through military and engineering networks, where it was translated into firmware updates, design modifications, and new prototypes. As a result, knowledge exploitation became the starting point of iterative learning cycles, in which use itself continuously regenerated the knowledge base rather than depleting it.

Aerorozvidka illustrates how wartime innovation both builds on and departs from established conventional processes of knowledge accumulation, storage, and use. Several elements correspond to the established stock-flow framework of knowledge management developed by Nielsen (2006): knowledge is systematically collected by mobile field teams (knowledge acquisition), stored in a knowledge exchange space within the

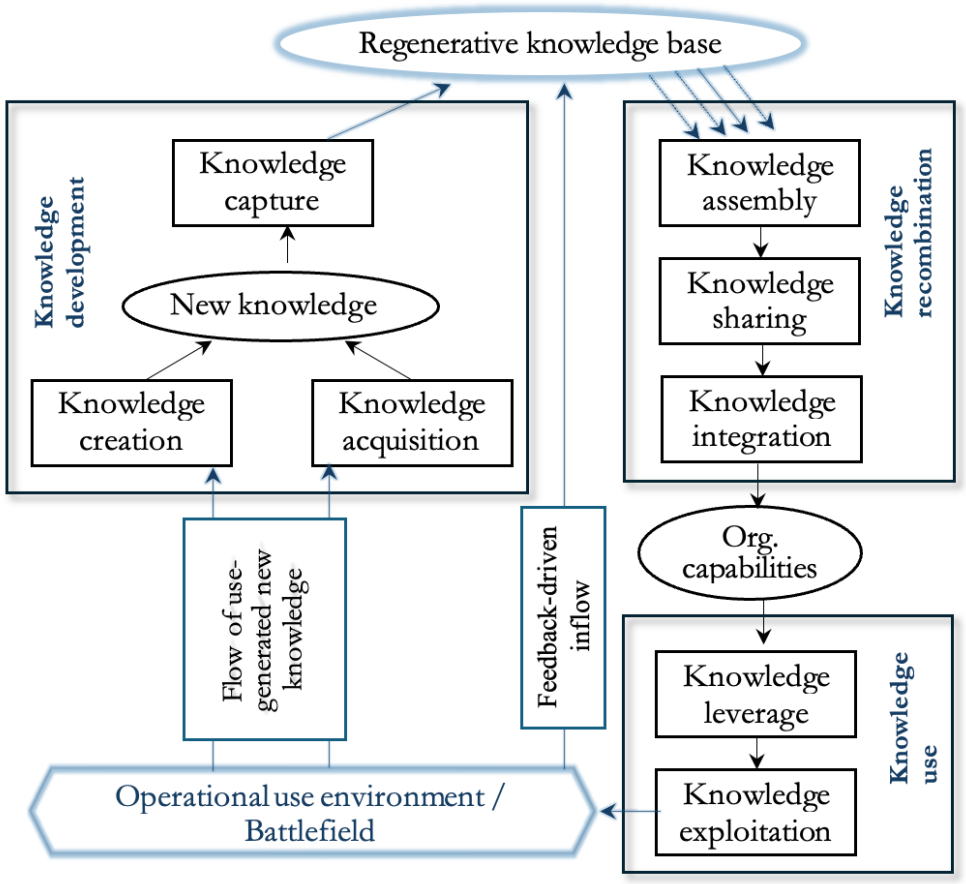
DELTA ecosystem[29] (knowledge stock), and embedded through training programs, doctrinal materials, and standardized operational practices (knowledge use).[30] These mechanisms support organizational learning in ways familiar from peacetime innovation systems.

At the same time, Figure 14 highlights a structural shift in the direction of knowledge flows. In contrast to peacetime settings, where exploitation depletes existing knowledge stocks, Aerorozvidka's battlefield deployments generate new knowledge directly (as they state: "developing new concepts"19). Battlefield deployment by lead users generates immediate feedback (tactical and technical insights) on performance and failure, which feeds directly back into the existing knowledge base and prompts rapid redesign of existing military technological solutions. At the same time, combatting exploitation could also drive the inflow of use-generated new knowledge. Knowledge use thus becomes inseparable from knowledge inflow, produc-

29 DELTA is an ecosystem of different military products, https://www.act.nato.int/article/delta-system-cwix/

30 NGO "AEROROZVIDKA", https://aerorozvidka.ngo/en/direction/knowledge-management

FIGURE 14: Wartime regeneration of the knowledge base.
Notes: Build on Nielsen's (2006) and Brychko, M., & Braunerhjelm, P. (forthcoming).



ing a regenerative cycle in which each deployment round enriches the underlying knowledge base rather than depleting it.

This pattern is consistent with prior work emphasizing knowledge creation through action under uncertainty (Arrow, 1974) and the continual revision of opportunity beliefs through experience (Choi, 1993). In Ukraine's wartime context, close integration with frontline feedback loops allowed small,

volunteer-origin organizations to adapt faster than established incumbents, generating a regenerative knowledge advantage rooted not in accumulated R&D resources but in repeated cycles of use-driven learning and recombination.

Recognizing the rapid obsolescence of existing knowledge stocks under combat conditions, international defense firms have increasingly turned to frontline testing to renew and validate their capabilities. Through initiatives such as Test in Ukraine, 45 foreign producers[31] access real-world use environments that generate feedback unattainable in laboratories or training ranges. Additionally, the Lithuanian firm Granta Autonomy[32] (NATO drone producer) collaborated with Ukrainian brigades to test drones under intense electronic warfare, where countermeasures evolve continuously. Participation in these frontline feedback loops enables firms to update technologies iteratively, preserving operational relevance through ongoing, use-based learning.

31 DSEI Gateway News, 15 August 2025, https://www.dsei.co.uk/news/test-ukraine-initiative-attracts-45-international-companies

32 Business Insider, 15 August 2025, https://www.businessinsider.com/drone-company-nato-says-testing-in-ukraine-key-sends-ceo-2025-8

The Ministry of Defence of Ukraine, together with the Ministry of Digital Transformation of Ukraine, the Armed Forces of Ukraine, the Scientific Research Institute of Military Intelligence, and the U.S. technology company Palantir launched the Brave1 Dataroom,[33] providing domestic and international firms with secure access to operationally grounded military data for training and validating AI solutions. That enables knowledge renewal through the recombination of existing firm capabilities and dismissing outdated assumptions through frontline-derived datasets. In this way, firms can continuously regenerate their knowledge bases, mitigating obsolescence and sustaining innovation under conditions of extreme uncertainty.

Civic-military interfaces, volunteer and NGOs initiatives in wartime innovation systems

Ukraine's wartime experience shows that civilian, NGO, and volunteer organizations' involvement in innovation is not a single phenomenon, but a set of distinct, complementary roles.

33 Ministry of Defense of Ukraine, 21 January 2026, https://mod.gov.ua/en/news/ministry-of-defence-launches-brave1-dataroom-a-secure-environment-for-training-military-ai-solutions

Together, these roles form a distributed innovation system that enhances resilience, accelerates learning, and sustains entrepreneurial activity under extreme stress.

One important category is civilians acting as information contributors, in which digital civic–military platforms transform societal awareness into operational knowledge. Rather than treating society as a passive audience, Ukraine embedded civilian knowledge flows directly into decision-making processes. The eVorog chatbot and the Shos letyt chatbot illustrate how civilian participation was rapidly transformed into operational capability through simple, but carefully designed, digital tools operated via the Telegram application on mobile phones.

Launched in March 2022 by the Ministry of Digital Transformation in cooperation with the Armed Forces, eVorog chatbot enables civilians to report the movement of enemy personnel and equipment through a standardized interface in just a few clicks. By dramatically lowering the cost of participation, the platform effectively turned ordinary citizens into distributed sensors, expanding situational awareness beyond formal intelligence

assets. Over 628,000 Ukrainians have used the chatbot,[34] with some submitting hundreds of verified reports. Military officials call eVorog "critical supplementary eyes", especially during the beginning of a full-scale invasion and in temporarily occupied areas with limited conventional surveillance.

Complementing the ground threat system notification, the Shos letyt chatbot, developed by Lviv Regional Military Administration specialists and IT specialists at the request of "Zahid" Air Command, focuses on real-time reporting of aerial threats, including missiles, drones, and aircraft. Reports submitted via the chatbot are immediately transmitted to the Armed Forces of Ukraine, contributing to early warning and threat assessment. A key institutional feature of Shos letyt is mandatory user authentication through the national digital identity platform, Diia. The institutional design of these platforms introduces a crucial layer of trust and accountability, helping to ensure data reliability while maintaining broad civic participation.

34 Kyiv Global Government Technology Centre, https://www.kyivgovtechcentre.org/government-defence-technologies

Beyond digital reporting platforms, Ukraine's wartime innovation system also relied heavily on production-oriented NGOs and volunteer non-profit organizations that directly contributed to the development, adaptation, and deployment of military technologies. Unlike traditional NGOs focused on fundraising and humanitarian support (such as evacuation, food distribution, medical aid) or logistics,[35] these organizations acted as de facto micro-manufacturers and system integrators, operating at the intersection of civic initiative, engineering expertise, and frontline demand.

One illustrative example is Escadrone,[36] a Ukrainian volunteer non-profit founded in 2022 in direct response to the full-scale invasion, famous for its Pegasus and Mammoth attack drones. The initiative was launched by a small group, including an investor who shifted from fundraising to self-financed production after early donation efforts proved insufficient

35 UK Humanitarian Innovation Hub, "Enabling the local response: Emerging humanitarian priorities in Ukraine, March–May 2022", https://humanitarianoutcomes.org/sites/default/files/publications/ukraine_review_2022.pdf

36 NGO "Escadrone", https://escadrone.com.ua/

to meet frontline needs. Escadrone began with small-batch assembly of FPV drones using commercially available components, prioritizing rapid prototyping and continuous feedback from deployed units over formal R&D processes.[37] Its rapid scaling from dozens to hundreds and later thousands of units per month[38] illustrates a wartime innovation mechanism in which founder initiative, use-based learning, and close alignment with operational demand substitute for capital intensity and pre-existing industrial capacity. Over time, its activities were integrated into the government's Army of Drones initiative, shifting from informal donation-based supply to structured procurement channels under the Defense Procurement Agency, including the DOT-Chain marketplace. This institutional integration enabled national-level scaling without eliminating decentralized, volunteer-driven production.

37 Euromaidan, "Inside Ukraine's secret FPV drone labs racing to stay ahead of Russia", 25 January 2024, https://euromaidanpress.com/2024/01/25/how-fpv-drones-became-ukraine-top-weapon/

38 The Ukrainian Drone Ecosystem Directory, https://www.drone-directory.com.ua/profile/escadrone/

Wild Hornets[39] similarly evolved from a volunteer initiative into a production-oriented organization focused on FPV drones, contributing not only to assembly but also to iterative design improvements informed by battlefield conditions.[40] The organization strengthened domestic supply resilience by localizing approximately 65 percent of its procurement of drone components, combining in-house electronics assembly with externally sourced high-quality battery cells from established international suppliers (Samsung and Westinghouse).[41]

Other volunteer and non-profit initiatives followed similar trajectories, forming a distributed layer of shadow industrial capacity that complemented formal defense producers.

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39 "Wild Hornets" was founded in spring 2023 as a volunteer-driven initiative. It leverages donations from individuals, corporate partners, and international funds to sustain operations, including scaling production through 3D printing farms and in-house component manufacturing, https://wildhornets.com/en/

40 Forbes, "Ukrainian Wild Hornets Co-Founder Talks About The Future Of Drone Wars", 26 March 2024, https://www.forbes.com/sites/davidhambling/2024/03/26/ukrainian-wild-hornets-co-founder-talks-about-the-future-of-drone-wars/

41 3D Printing Industry, "Ukraine Deploys 3D Printed Drones to Combat Russian Shahed Swarms", 25 July 2025, https://3dprintingindustry.com/news/ukraine-deploys-3d-printed-drones-to-combat-russian-shahed-swarms-242362/

Importantly, these organizations were not peripheral suppliers; they became embedded within operational learning loops, responding directly to requests from military units and adapting designs in short cycles. These volunteer producers also helped mitigate systemic risk. By distributing production and innovation across many small actors, Ukraine reduced its vulnerability to single-point failures caused by missile strikes, infrastructure disruption, or supply-chain breakdowns. This decentralization enhanced resilience while sustaining continuous technological adaptation.

In addition to production, several civilian and NGO actors also played a decisive role as wartime capital allocators, shaping technological trajectories through selective financing rather than passive donation flows. The Come Back Alive Foundation[42] and the Serhiy Prytula Charity Foundation,[43] among many

42 Charitable foundation "Come Back Alive" founded in 2014, https://savelife.in.ua/en/about-foundation-en/

43 The Serhiy Prytula Charity Foundation was established in July 2020 by Ukrainian TV presenter and volunteer Serhiy Prytula. Initially focused on non-military projects, it shifted to providing large-scale military and humanitarian aid following the full-scale Russian invasion of Ukraine in February 2022, https://prytulafoundation.org/en/about

others, actively redirected resources toward drone configurations that demonstrated resilience to electronic warfare and operational effectiveness, withdrawing support from underperforming designs based on frontline feedback. In this capacity, civilian organizations operated less like traditional charities and more like decentralized venture capital under fire, accelerating diffusion of effective solutions while disciplining poor performance in the absence of conventional market signals.

In parallel, civic actors played a critical role as trainers and capability diffusers, addressing one of the most binding constraints in wartime innovation: skilled human capital. Volunteer-led training initiatives and NGO-affiliated technical schools provided accelerated instruction for both military and civilian UAV operators, maintenance specialists, and electronics technicians. Organizations such as the Come Back Alive Foundation (through the Yatahan UAV school for military personnel)[44] and Victory Drones (free courses for the military, civilians, and

44 Come back alive, “Evolution of the 'Yatagan' School: New Opportunities for UAV Operator Training”, 06 February 2025, https://savelife.in.ua/en/materials/news-en/evolution-of-the-yatagan-school-new-oppo-en/

producers)[45] provided accelerated, practice-oriented training in FPV, reconnaissance, and strike-drone operations, serving as a substitute for slow-paced peacetime military training pipelines.

A growing number of civilian and NGO-run training centers, including the KRUK UAV Operator Training Center,[46] the Boryviter Military School,[47] the VYRIY Tech School,[48] and the Dronarium Academy,[49] among others, were mobilized to rapidly onboard

45 Learn with "Victory Drones", https://en.victory-drones.com/

46 The KRUK UAV Operator Training Center (established in April, 2022) has trained over 8,000 UAV operators & related specialties experts, https://kruk.in.ua/en

47 Boryviter Military school (established in April, 2022) has trained over 34,000 service members in various training courses including UAVs, management and leadership for commanders and staffs at the battalion/battalion tactical group/regimental level, troop leading procedures, map reading and land navigation, radio communications, situational awareness systems and others, https://boryviter.org.ua/en/home/

48 VYRIY Tech School trains specialists for future employees at VYRIY, a Ukrainian Military Tech company, https://www.vyriy.school/

49 Dronarium Academy is an educational and research platform that covers the full cycle of work with unmanned systems and counter-UAS technologies. Prior to 2022, the organization specialized in civilian applications, including aerial photography, infrastructure monitoring, geodesy, and agricultural services. Since it has trained over 17,000 UAV pilots deployed across frontline units, https://www.dronarium.academy/en/about-us

drone operators and technical specialists in response to urgent operational demand. By 2024, the Ministry of Defence of Ukraine had formally certified more than 30 such schools,[50] signalling a deliberate policy choice to integrate volunteer-driven training into national defense capability rather than treat it as an auxiliary or temporary measure.

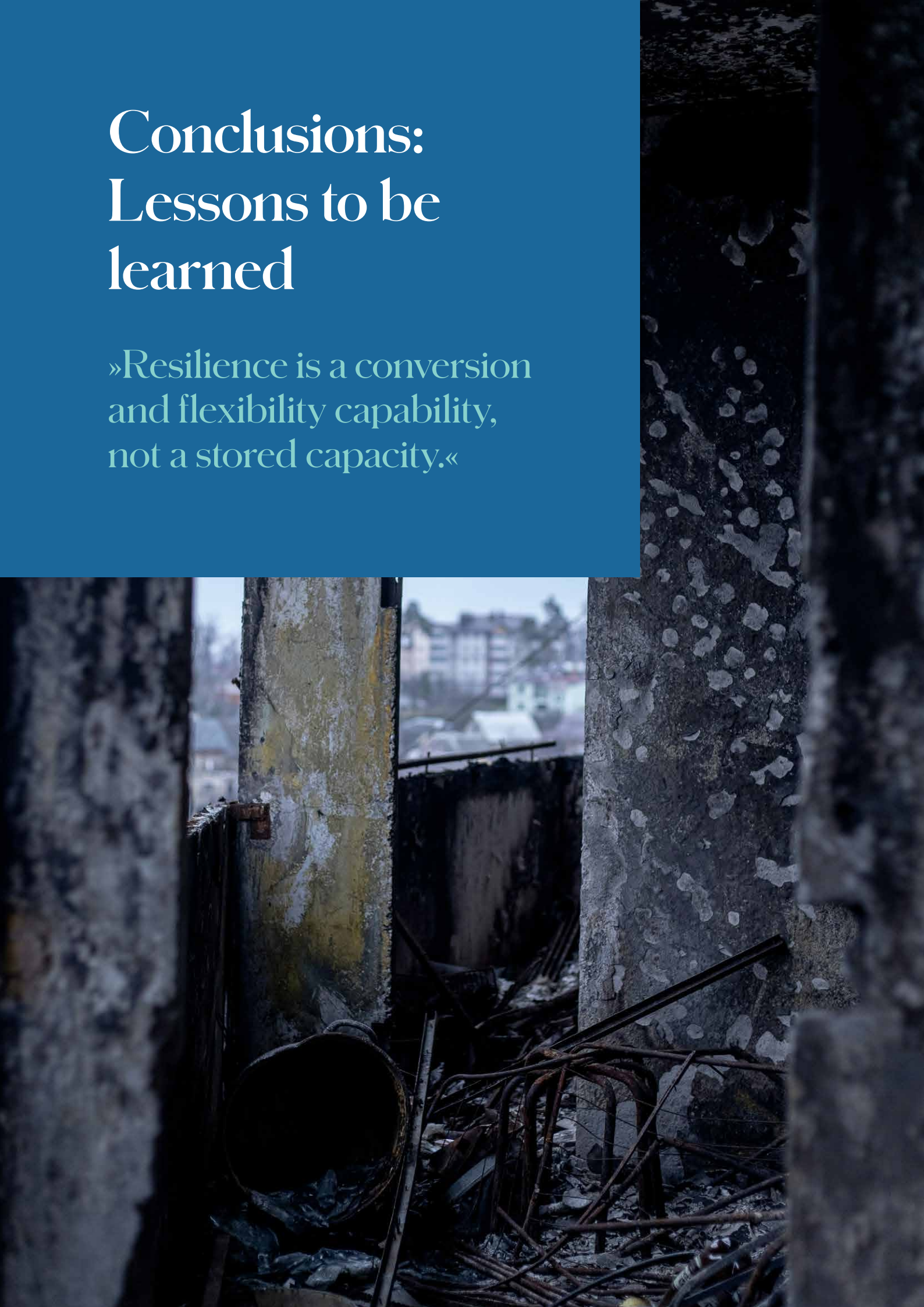
By distributing innovation, production, and training across hundreds of civilian and hybrid actors, Ukraine reduced systemic

50 Ministry of Defense of Ukraine, 21 November 2024, https://mod.gov.ua/en/news/the-ministry-of-defence-has-certified-over-30-schools-for-drone-operators

vulnerability to targeted attacks, infrastructure failures, and supply-chain disruptions, turning decentralization into a core source of resilience. At the same time, such systems rely heavily on trust, digital security, and sustained coordination, and may generate governance challenges if maintained beyond emergency conditions without clear institutional frameworks.

Conclusions: Lessons to be learned

»Resilience is a conversion and flexibility capability, not a stored capacity.«



Ukraine's wartime experience does not offer a blueprint to be copied. It does, however, provide rare empirical evidence on how industrial capacity and innovation emerge under severe constraints on time, capital, and institutional slack. In the UAV sector, Ukraine was forced to improvise, adapt, and reorganize production under sustained pressure, revealing mechanisms that are normally obscured in peacetime systems. The lessons that follow are therefore not prescriptions drawn from a single case, but design principles derived from observed wartime dynamics that can inform how other countries structure innovation, procurement, and industrial preparedness for high-uncertainty environments.

LESSON 1. Resilience is a conversion and flexibility capability, not a stored capacity.

The rapid expansion of Ukraine's UAV output was driven primarily by firms that did not exist before the crisis and entered at a micro scale, yet were integrated into production within months through use-based validation and procurement recognition. More than half of wartime entrants began as microenterprises, and post-2022 micro firms upgraded to small-scale status at nearly twice the rate of pre-war incumbents, despite limited

access to capital and infrastructure. Industrial resilience should be understood not as stored capacity within incumbent firms, but as the ability to activate, test, and selectively scale dispersed civilian, SME, and dual-use capabilities when threat levels rise, with performance in use, not prior size, determining who grows.

LESSON 2. Scaling beyond small firms requires targeted risk-sharing instruments

Ukraine's data indicate rapid micro-to-small-scale scaling, but persistent barriers to large-scale production. Capital intensity, infrastructure risk (energy, transport, supply chains, etc.), and supply-chain fragility remain binding constraints. This highlights a larger issue that innovation without scale does not deliver sustained capability. Therefore, if the policy goal is industrial scale, governments need de-risk scaling instruments beyond deregulation.

LESSON 3. Distributed and modular production increases survivability and adaptability.

Ukraine's UAV ecosystem shows a shift from a legacy, manufacturing-heavy structure toward a more modular, interconnected

system that combines manufacturing with hardware components, software, engineering services, and security functions. After 2022, core manufacturing regained weight, but within a broader ecosystem capable of recombination and substitution. This reduced vulnerability to targeted attacks, supply disruptions, and single-point failures. Policies should promote supplier redundancy, distributed production, and interoperable components.

LESSON 4. Procurement openness matters, but absorption capacity is the bottleneck

Despite reforms lowering barriers, wartime entrants' procurement participation in Ukraine remained much lower than incumbents. Outcomes are concentrated, with few firms securing most contracts. This shows a tension: the innovation system encouraged entry and experimentation, but formal procurement systems favored actors with administrative capacity, experience, and routines. The state must actively support new producers, especially SMEs and first-time entrants, by providing assistance with documentation, compliance, and logistics. Procurement should begin with pilot contracts, moving to

framework agreements, and then scaled procurement, serving as both a learning process and a filter, not just a transaction tool.

LESSON 5. State recognition should follow a clear escalation ladder

Ukraine's wartime system exhibited an ordered structure of wartime recognition: tender wins are strongly associated with later access to public funding, and funding recipients are more likely to become funding managers. At the same time, the most responsibility-intensive roles remained concentrated among incumbents. This reveals a workable governance logic in crisis: combine rapid inclusion at lower tiers with conservative delegation at upper tiers to preserve accountability. Hence, rather than treating procurement, public funding, and fund-management roles as separate tools, governments should explicitly design recognition ladders that (i) bring new entrants into the system early, (ii) validate through performance, and (iii) reserve high-trust roles for actors that demonstrate capacity, while creating upgrading routes so capable new entrants can progress.

LESSON 6. Volunteer and civic actors can be structurally important even when numerically small

Although volunteer and NGO producers account for only a marginal share of registered entities, their contribution to wartime innovation is structurally significant. These actors translate frontline needs into rapid design iteration, accelerate knowledge diffusion, allocate resources under extreme uncertainty, and expand training capacity when formal systems are constrained. By diversifying both production and knowledge channels, civic and volunteer actors enhance system resilience precisely when state and market institutions face overload.

LESSON 7. Digital infrastructure makes decentralized innovation governable

Ukraine's wartime innovation ecosystem shows that when the government provides shared digital infrastructure and clear operational frameworks, innovation can be widely decentralized without undermining strategic oversight. Digital platforms, such as Brave1, DOT-Chain Defense, Zbroya Smart Force, made it possible to decentralize experimentation and entry, while

allowing the state to monitor performance, channel feedback, and selectively scale solutions that proved operationally effective.

LESSON 8. Frontline feedback must be institutionalized as a standing knowledge engine

Ukraine's experience demonstrates that frontline feedback was widely used to support rapid adaptation and design iteration, but only partially integrated into formal procurement and scaling decisions. This points to the need to institutionalize feedback from operational use so that it systematically informs validation, selection, and procurement, rather than remaining primarily an informal or ad hoc input under crisis conditions.

Appendix

Appendix A: Classification of entities in Ukraine's UAV ecosystem based on NACE (1991–2025)

Tier	Layer name	Main NACE code	Official title	Rationale for inclusion in UAV ecosystem	Number of observations
1	Manufacturing (dual-use aerospace)	30.30	Manufacture of air and spacecraft and related machinery	Core UAV and drone airframe production; includes dual-use (civil + defense) UAV manufacturers and integrators.	2176
2	Manufacturing (armament & defense-specific)	30.40	Manufacture of military fighting vehicles	Covers armed or strike-capable UAV systems that integrate weapons or operate as unmanned combat platforms.	34
		25.40	Manufacture of weapons and ammunition	Represents production of loitering-munition payloads, warheads, and other explosive components integrated into armed drones.	60
3	Hardware subsystems & components	26.11	Manufacture of electronic components	Microchips, sensors, passive components used in UAV avionics and control systems.	48
		26.12	Manufacture of loaded electronic boards	PCB assembly for flight controllers, ESCs, autopilots, and telemetry boards.	25
		26.20	Manufacture of computers and peripheral equipment	Embedded computers, onboard processors, and ground-control computing hardware.	24
		26.30	Manufacture of communication equipment	Radio links, FPV transmitters, data-link modules, antenna systems.	64
		26.40	Manufacture of consumer electronics	FPV cameras, goggles, and control/display units common in volunteer and hobby FPV drone production.	6
		26.51	Manufacture of instruments and appliances for measuring, testing and navigation	IMUs, GPS receivers, altimeters, and inertial sensors for UAV navigation.	86
		26.70	Manufacture of optical instruments and photographic equipment	EO/IR cameras, gimbals, and LiDAR systems for targeting or reconnaissance payloads.	7
		27.11	Manufacture of electric motors, generators and transformers	Brushless motors and actuators for drone propulsion.	11
		27.20	Manufacture of batteries and accumulators	UAV battery packs and power-supply units.	81
		27.31	Manufacture of fibre-optic cables	Used for high-speed data transmission or tethered UAV systems.	1
		27.32	Manufacture of other electronic and electric wires and cables	Internal wiring harnesses, signal and power cabling for drones.	2

Tier	Layer name	Main NACE code	Official title	Rationale for inclusion in UAV ecosystem	Number of observations
		28.99	Manufacture of other special-purpose machinery	Ground-control stations, launch systems, test stands.	60
4	Software & data systems	62.01	Computer programming activities	Autopilot, guidance, targeting, AI, and swarm-control software.	522
		62.02	Computer consultancy activities	System integration, mission-software customization, and digital-twin simulation.	102
		63.11	Data processing, hosting and related activities	Drone telemetry processing, imagery analysis, and cloud-based control infrastructure.	57
5	R&D and prototyping activities	72.19	Other research and experimental development on natural sciences and engineering	R&D laboratories, prototyping groups, experimental UAV design and testing.	192
6	Engineering, testing, training & maintenance	71.12	Engineering activities and related technical consultancy	Design, aerodynamics, integration, and systems engineering.	114
		71.20	Technical testing and analysis	Flight-testing, certification, and component reliability analysis.	20
		33.16	Repair and maintenance of aircraft and spacecraft	Field repair, depot maintenance, retrofit of UAV platforms.	86
		85.59	Other education n.e.c.	Drone-operator training and technical education programs.	48
7	Civic (NGO, non-profit) & volunteer production	88.99	Other social work activities without accommodation	Non-profits and volunteer foundations that assemble or distribute drones for defense or humanitarian use.	2
		94.99	Activities of other membership organisations n.e.c.	Volunteer associations and civic groups engaged in drone development or logistics support.	5
8	Security & defense activities	80.20	Security systems service activities	Private or governmental integrators using UAVs for surveillance or counter-UAV systems.	7
		84.22	Defence activities	Procuring UAVs.	9

Appendix B: Measurement indicators and analytical framework

Firm scale is measured using size categories defined by the State Statistics Service of Ukraine, based on the form of financial reporting. Firms are classified into three ordered size categories: micro (0–9 employees), small (10–49 employees), and medium and large (+50 employees), which correspond to standardized reporting regimes broadly aligned with EU statistical practice. Consistent with OECD firm dynamics research, these size classes are treated as meaningful proxies for differences in productive capacity (Cabral & Mata, 2003).

The analysis on firm size relies on an unbalanced firm-level panel covering 2018-Q2 to 2025. Irregular reporting is a common feature of firm registries. In line with OECD guidelines on longitudinal firm data, missing observations are not imputed (OECD, 2015). Instead, the analysis uses only observed size classifications, thereby avoiding the introduction of artificial growth paths or spurious stability through interpolation (Criscuolo et al., 2014).

To examine post-entry dynamics, firm-size trajectories are constructed by arranging observations in chronological order for

each company. Size transitions ($S_t \rightarrow S_t\cdot$) are defined only between adjacent size states. Missing years are therefore treated as gaps rather than as states. This ensures that transitions capture genuine changes in firm scale, even when reporting is discontinuous (You & Papps, 2022).

For example, an entity classified as small in 2020, unobserved in 2021, and classified as medium/large in 2022 is recorded as having undergone an upward size transition over the observed interval. While the precise timing of the adjustment cannot be determined, the direction of change is unambiguous. By doing this, the procedure avoids making assumptions about the missing period and prevents long gaps from breaking the firm's trajectory or creating artificial stability.

Post-entry dynamics are analyzed by tracking how firms move between size categories over time, separately for pre-2022 incumbents and post-2022 entrants. For each cohort, firms are followed from one observed period to the next and classified according to whether they grow into a larger size category (upgrades), shrink into a smaller one (downgrades), or remain at the same size category (static transitions). Transition probabilities are calculated as the share of observed transitions

from a given origin size that result in each destination size. This approach enables comparison of patterns of early firm development across cohorts without imposing assumptions about continuous growth paths or uniform reporting intervals.

Differences in entry composition and post-entry dynamics between cohorts are assessed using Pearson's chi-square tests, comparing both the distribution of initial firm size categories at entry and the frequencies of observed size transitions. This non-parametric approach identifies structural shifts in industry entry and early firm growth patterns.

Procurement participation and success

State recognition of the role played by incumbents and entrepreneurs, respectively, is measured using three observable channels that reflect increasing levels of engagement between entities and the state during wartime. First, public procurement is used to identify both access and initial recognition by distinguishing entities that submitted at least one tender bid during 2023–2025 and those that secured (won) at least one contract. Second, deeper financial involvement is captured through an indicator for public funding received, highlighting entities that

received state funding transactions during the period. Third, the highest level of engagement is measured through public funds managed on behalf of the state.

Procurement outcomes are assessed by distinguishing between participation and success conditional on participation. Using tender-level data for 2023–2025, participation is defined as submitting at least one bid, and success is measured as the number of tenders won relative to the number submitted. Aggregate win rates are therefore calculated conditional on bidding, abstracting from differences in the size of the underlying firm population. This measure captures effectiveness in procurement conditional on engagement, rather than overall market penetration.

To capture the distribution of outcomes among successful participants, the analysis compares the median and mean number of tenders won among entities that secured at least one contract. The divergence between the mean and median values is interpreted as evidence of outcome concentration, in which a limited subset of firms accounts for a disproportionate share of contracts.

To investigate the mechanisms underlying the observed concentration patterns, bidding behaviour among successful firms is analyzed. For entities that won at least one tender, the

average number of bids submitted and the average contracts won are computed by cohort and organizational form. This allows the analyses to distinguish between high success rates driven by large-scale participation and those resulting from selective bidding strategies.

Observing that some firms win many public contracts is insufficient to identify the underlying mechanism driving concentration, particularly in wartime procurement. High contract counts may arise from either extensive participation, in which firms submit many bids and win a modest share, or from selective bidding, in which firms bid infrequently but achieve high success rates. By jointly analyzing the number of bids submitted and contracts won among successful firms, we distinguish between these mechanisms: scale-driven success is characterized by high bid volumes and moderate win rates, whereas selectivity-driven success is characterized by fewer bids with systematically higher conditional win probabilities. This distinction is especially salient in wartime settings, where capacity constraints, urgency, and information asymmetries may favor targeted participation over broad competition, shaping the structure of procurement concentration.

Wartime government recognition

Due to data availability, the timing of state recognition can be observed only from 2023 onward. Accordingly, an attention lag indicator is constructed as the difference between a firm's registration year and 2023, the first year of observability for tender wins, funding receipts, or funding management. An attention lag of zero indicates that a firm was recognized within the first year of the wartime observation window.

This indicator is not intended to measure absolute time-to-recognition across the full firm life cycle. In particular, post-2022 entrants mechanically exhibit an attention lag of zero by construction. Instead, the measure is used to examine how the state selected and mobilized existing industrial capacity once wartime procurement and funding mechanisms were activated.

Structure of the wartime government recognition

To examine whether wartime recognition follows an ordered structure rather than random allocation, the analysis applies two complementary empirical strategies. First, an

overlap (nestedness) analysis is conducted to assess the extent to which deeper forms of engagement with the state (e.g., receiving public funding or managing public funds) are observed among entities that have already achieved more basic forms of recognition, notably success in public procurement. This approach identifies whether recognition channels tend to accumulate within the same firms, indicating systematic co-occurrence rather than independent assignment.

Second, conditional probability analysis is employed to evaluate whether access to deeper forms of engagement is more likely following earlier recognition. Specifically, the analysis compares the probability of receiving public funding among tender winners versus non-winners, and the probability of assuming funding management roles among funding recipients versus non-recipients. These conditional comparisons allow assessment of whether wartime recognition is sequentially related across channels.

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