**Reducing Risks in Wartime Through Capital-Labor Substitution: Evidence from World War II**

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Abstract

Our research uses data from multiple archival sources to examine substitution among armored (tank-intensive), infantry (troop-intensive), and airborne (also troop-intensive) military units, as well as mid-war reorganizations of each type, to estimate the marginal cost of reducing U.S. fatalities in World War II, holding constant mission effectiveness, usage intensity, and task difficulty. If the government acted as though it equated marginal benefits and costs, the marginal cost figure measures the implicit value placed on soldiers' lives. Our preferred estimates indicate that infantrymen's lives were valued in 2009 dollars between $0 and $0.5 million and armored troops' lives were valued between $2 million and $6 million, relative to the efficient $1 million to $2 million 1940s-era private value of life. We find that the reorganizations of the armored and airborne divisions both increased efficiency, one by reducing costs with little increase in fatalities and the other by reducing fatalities with little increase in costs.

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Governments spend large amounts each year to increase the safety and effectiveness of ground combat troops; however, little is known about the degree to which their expenditures translate into measureable improvements in survival or combat success. Our research uses data from multiple archival sources to understand the economics of ground combat and tradeoffs made by American military planners between expenditures and U.S. deaths in one important historical context –the Western Front of World War II (WWII). The cost per life saved is estimated and used to infer the dollar value that the U.S. government placed on avoiding military deaths and determine how that valuation compared with the private Value of a Statistical Life (VSL) at the time – citizens' willingness to pay for reductions in fatality risk (Thaler and Rosen, 1975; Viscusi, 1993, 1996).

U.S. Army Ground Forces were organized into divisions, military units consisting of 8,000 to 20,000 troops, that were infantry (troop-intensive), armored (tank-intensive), or airborne (paratrooper, also troop-intensive). In late 1943, Army policies reduced the size of the armored division and slightly reduced the size of the infantry division. In early 1945, another Army policy increased the size of the airborne division. Our research considers the effects of substitution across the different pre- and post-reorganization division types. Tank-intensive units were expensive in dollars, but troop-intensive units put more human targets on the battlefield; hence, an increase in tank-intensity would raise dollar costs and reduce fatalities. If the U.S. government acted as though it equated marginal benefits and marginal costs, the marginal cost per reduction in fatalities measures the implicit value the government placed on soldier's lives.

We compiled the data set we use from multiple sources, and it constitutes the most extensive set of quantitative information available on military operations in a single war. Included are individual-level data on all 144,534 deaths to American ground divisions in WWII that were hand-typed from archival lists and combined with casualty rosters obtained from multiple government agencies. All Allied and Axis units' movements come from campaign histories and historical atlases to identify terrain, geographical progress, and which Allied and Axis units met in combat. Another set of archival sources we compiled measure the costs of raising and operating different U.S. divisions in WWII. Finally, we also use data compiled by The Dupuy Institute from U.S. and German archival sources on both sides' combat experiences for 162 engagements.

The results from our research indicate that, at the tank-intensity levels of the infantry and airborne divisions, the marginal cost in 2009 dollars per life saved by increasing tank intensity was $0.5 million or less, as compared to VSL estimates of $1 million to $2 million for young men in 1940 (Costa and Kahn, 2004). At the higher tank-intensity level of the armored division, we find a higher cost per life saved that is generally greater than $2 million. Thus, our results suggest that the U.S. government implicitly undervalued infantrymen's lives and slightly overvalued armored personnel's lives relative to the private value of citizens at the time. We find that the reorganization of the armored division increased efficiency by reducing dollar costs with little increase in fatalities and that the reorganization of the airborne division increased efficiency by generating a large reduction in fatalities at a low cost.

It is important to recognize that our research does not directly estimate the VSL for U.S. military personnel during WW II. It is more akin to the cost per life saved estimates used for various government regulations (Morrall III 2003). It is unclear whether military members at the time valued their lives differently in comparison to non-military workers. Given the widespread reach of the draft, it is likely that they were roughly the same. There does not appear to be any previous research on estimating the VSL for WW II military personnel. As for other conflicts, Rohlfs (2012) estimates an upper bound on the VSL for military recruits during the Vietnam era and finds values ranging from $7 million to $12 million (in 2009 dollars). In addition, recent estimates from Greenstone et al. (2014) suggest that modern day military members tend to implicitly value their lives at levels lower than average citizens. Also, given the limited amount of applicable research, it is not entirely clear whether military members have traditionally been under- or over-valued by the U.S. government relative to private citizens. Recent estimates in Rohlfs and Sullivan (2013), for modern day warfare, suggest that the U.S. government likely over-values military members in comparison to average citizens for certain types of armament programs. Recent relative over-valuation of life saving in the military may or may not be the case historically, and our research provides context for issues related to the economics of military decisions where soldiers' lives are at stake.[3]

## II. Key Institutional Factors

After World War I, British military theorists advocated increasing the use of tanks to avoid the casualty-intensive stalemate of trench warfare (Fuller, 1928, pp. 106-151; Liddell Hart, 1925, pp. 66-77; Wilson, 1998, pg. 120). The British theorists' ideas were influential in the U.S. Army and in Congress (U.S. Congress, 1932, pg. 9932). However, the Army was slow to adopt tanks due to conservatism among high-ranking officers and Congressional budget cuts (Greenfield, Palmer, and Wiley, 1947, pp. 334-335; Steadman, 1982; Watson, 1950, pp. 15-50).

[3] In addition to addressing the U.S. government's implicit valuation of soldiers' lives, our study adds to the tools available for empirical research in national defense. The WWII data used here describe a wide variety of combat situations and are unique among datasets from modern wars in that they include detailed first-hand information from both sides. Casualty forecasts using previously available WWII data have been more accurate than those based on less data-driven approaches (*Economist*, 2005), and the data and techniques we introduce here could help to further improve the accuracy of many types of military resource deployment policy evaluations.

## A. Determinants of Army-Wide Capital Intensity During World War II

During the war, military procurement was constrained by the size of the U.S. economy and population (Smith, 1959, pp. 136; 154-158); however, the procurement process was driven more by planners' perceived tradeoffs than by responses to immediate shortages (Harrison, 1988, pp. 181, 188-9). Constraints that the War Production Board imposed on materiel procurement were denominated in dollars and took into account "the needs of the civilian and industrial economy" (Smith, 1959, pg. 154-8). Most materiel purchases involved large contracts whose prices were monitored to curb war profiteering (Smith, 1959, pp. 216-412) but appear to have been somewhat higher than prices in the civilian economy.[4]

As with equipment, troop procurement involved a variety of tradeoffs. The Army adjusted its new soldiers' physical and intellectual competency requirements depending on the need for troops, and Congress restricted the drafting of 18-year-olds and fathers in response to public sympathy but varied draftee restrictions depending on the needs of the war effort (Greenfield, Palmer, and Wiley, 1947, pp. 246-251; Palmer, Wiley, and Keast, 1959, pp. 45, 85, 201-207, 400).

## B. Division Types and the Reorganizations

The division was the primary level at which U.S. Army Ground Forces were organized. Roughly two to four divisions comprised a corps, which was the next higher level of organization. Divisions from the same corps were rarely more than a few miles apart. Divisions' corps affiliations changed frequently over the course of the war, and a corps sometimes included

[4] With all prices in 2009 dollars, in 1942, the Army paid $18,300 for a four-door sedan and $16,000 for a ¼-ton jeep (U.S. Army Service Forces, 1942). One source shows a new two-door sedan selling in the civilian economy in 1940 for $11,300; comparable new and used cars sold in nearby years for similar prices. In 1935, a used half-ton pickup truck was selling for $7,300, and in 1956, a new jeep was selling for $10,800 (Morris County Library, 2009).

divisions from multiple countries (Greenfield, Palmer, and Wiley, 1947, pg. 332; Kahn and McLemore, 1980, pp. 192-199).

The Army sent 16 armored divisions, 47 infantry divisions, and 4 airborne divisions to the Western Front. Offensively, armor use could exploit penetrations generated by infantry and often operated behind enemy lines but required large amounts of gasoline and had difficulty on wet or rugged terrain. A wide set of both offensive and defensive operations used infantry, and airborne divisions parachuted behind enemy lines to disrupt communications and supplies and to initiate surprise attacks (Evans, 2002, pg. 49; Gabel, 1985a, pg. 4-6, 24; 1985b, pg. 4, 1986, pp. 4, 8, 12, 23; Rottman, 2006, pp. 6, 24-7; Stanton, 1984, pg. 8, 11; Zaloga, 2007, pp. 9-12).

Technological progress at the time allowed U.S. commanders to advance and maneuver their troops much faster during WW II than in previous wars. The degree of movement, however, was largely dictated by the terrain, combat environment, and unit capabilities. The initial entry of U.S. forces into the war began in November, 1942 in Algeria and Morocco. Units traveled east across Africa, up to Tunis and Sicily, and continued up the length of Italy for the duration of the war. Additional Allied units invaded Northern France in June 1944 and Southern France in August 1944, both traveling eastward to Germany.

When the U.S. first entered the war, the number of troops in a standard infantry division was 15,514, and the number in a standard armored division was slightly lower, at 14,643; the armored division also included 390 tanks. The airborne division was first introduced in October 1942 and included 8,505 troops, making it considerably smaller than the other division types. The actual numbers of troops and tanks in a division varied over time as subordinate units, such as regiments and battalions, were attached to and detached from different divisions. Attaching units was more common than detaching them, so that the numbers of troops and tanks in a division tended to be larger than the standard levels. Troops and tank levels also varied due to the lag between combat losses and the arrival of replacement troops and equipment.

In July 1943 the Army slightly reduced the size of the infantry division to 14,253. In September 1943 the Army reduced the troops and tanks in the armored division to 10,937 and 263. In December 1944 the Army increased the number of troops in an airborne division to 12,979 (Wilson, 1998, pp. 162-9, 183-5, 197). The new structures help identify the military's implicit value of soldiers' lives.

All armored and infantry divisions that were raised after the reorganizations were given the new structure. All six infantry divisions already in the theater were reorganized in late 1943 or early 1944. Of the three armored divisions that were already in the theater, the 1st was reorganized in June, 1944. The 2nd and 3rd were kept under the old structure to avoid disrupting their preparation for the D-Day invasion and were not reorganized until after the end of the war. The airborne reorganizations all took place on March 1, 1945. Of the four airborne divisions –the 13th, 17th, 82nd, and 101st –that were sent to the Western Front, the attachments to the 82nd and 101st were sufficiently large prior to the reorganization that they were effectively under the larger structure since the start of the war (Stanton, 1984, pp. 5-19; Wilson, 1998, pp. 182-96).

## III. Descriptive Results

The datasets we use here include a daily panel constructed by us and a team of research assistants. The data include information about the overseas experiences of every U.S. division sent to the Western Front and a sample obtained from The Dupuy Institute of a more detailed set of variables for 289 division days from 162 engagements between U.S. and German forces. In addition, our research team compiled data from archival sources on the costs of raising and operating divisions of different types. Descriptions and summary statistics for all our datasets appear in an appendix available from the authors.

Figure 1 shows numbers of U.S. troops, tanks, estimated cost, and combat outcomes by division type. Panels A and B show actual troop and tank levels from the engagement data. Within each panel the left three bars are pre-reorganization levels and the right three bars are post-reorganization. The black bars correspond to armored divisions, the white bars to infantry divisions, and the gray bars to airborne divisions. The 2$^{nd}$ and 3$^{rd}$ Armored Divisions are always treated as pre-reorganization, and the 82$^{nd}$ and 101$^{st}$ Airborne Divisions are always treated as post-reorganization.

As the engagement data illustrate, reorganization led to considerably smaller armored divisions. The reorganization reduced the typical armored division's numbers of troops and tanks from 20,000 and 467 to 15,100 and 218. This was in stark contrast to the impact of the reorganization's effect on the size of other division types. For instance, the reorganization appears to have had little impact on the size of infantry divisions. The engagement data do not include information on the size of the pre-reorganization airborne units. We do find, however (in results not shown), that the standard and authorized troop level data indicate that the reorganization led to considerably larger airborne divisions.

Panel C combines the per troop and per tank estimates from the cost data with the troop and tank levels from panels A and B to estimate the cost of a 10.8-month deployment by division type.[5] From the engagement data, we find that the 1943-1944 armored reorganization reduced the cost of an armored division from $5.14 billion to $2.93 billion ($2009) and that the infantry

[5] Light, medium, and heavy tanks are all treated equally in the cost calculations. The U.S. Army increased its percentage of medium versus light tanks over the course of the war and introduced a heavy tank design near the end of the war (Stubbs and Connor, 1969, pp. 63-6). In the engagement data, considering light tanks separately from medium and heavy tanks has little effect on the estimates in this study, as shown in the available appendix.

reorganization slightly increased the cost of an infantry division from $2.20 billion to $2.29 billion ($2009) for a 10.8 month deployment.

Panels D, E, and F present various measures illustrating how well U.S. troops performed in combat. Success measures include kilometers (km) of progress along the attacker's axis of advance, U.S. killed in action (KIA), and a zero to one subjective index of mission success from The Dupuy Institute (2001b, 2005) for each of the division types. The differences between armored and infantry divisions in the panels suggest that armor was more effective than infantry in combat.[6] The two best proxy measures that we use for "mission accomplishment" – km advanced and the mission success index –tend to be higher for the armored divisions than for infantry. Also of interest (in results not shown) is that task difficulty appears to have been higher for armored divisions as well. Although the number of troops in the opposing division was similar between pre-reorganization armor and infantry and somewhat lower for post-reorganization armor, the number of tanks in the opposing division was considerably higher for armor in both cases. U.S. KIA is slightly higher for armor than for infantry, which could be attributable to higher task difficulty or usage intensity for armor. Despite the decrease in the armored division's troops and tanks, we observe a slight increase in km of progress and little effect on U.S. KIA. We see a negative effect of the armored reorganization on the index of mission success in panel F, however, suggesting that mission effectiveness may have declined in a way that is not captured by geographical progress. For the infantry reorganization we observe slight increases in the mission success measure and in U.S. KIA.

Figure 2 illustrates the effects of the 1943-1944 reorganizations on usage in combat, geographical progress, and U.S. KIA in our second data set, the division by day panel. Panel A

[6] Regression results that duplicate the information in Figures 1 and 2 are available in the appendix available from the authors.

shows the average number of Axis divisions in the same 0.25 x 0.25-coordinate (about 15 by 15 mile) cell as the division, and panel B shows the fraction of division days with five or more U.S. KIA. Airborne divisions had relatively high rates of exposure to Axis divisions, and infantry divisions had high numbers of days with five or more U.S. KIA. According to both definitions of days of combat, the armored and airborne reorganizations came with decreases in combat days for the two division types, and the infantry reorganization came with an increase in combat days for the infantry division type. The changes in combat days are reflected in the outcome measures, km of progress and U.S. KIA, for the full sample in panels C and D. The armored reorganization is associated with a slight increase in progress and a large decrease in fatalities for the armored division type, a result that is consistent with a decline in days of combat or the difficulty of tasks for which the armored division was used. A similar and more pronounced pattern can be seen for the reorganization of the airborne division, a result consistent with a decline in combat days or task difficulty for the airborne division type as well. The opposite pattern can be seen for the infantry reorganization, which shows a decline in progress and an increase in KIA, a finding that is consistent with an increase in combat days or task difficulty for infantry.

Panels E and F show the same outcome variables as in panels C and D; however, the sample is restricted to days in which the U.S. division was in the same geographic cell as one or more Axis divisions. For the division days with nearby Axis units in panels E and F, progress is similar for armored and airborne and is slightly lower for infantry divisions. Also, for division days with nearby Axis units, the results show U.S. KIA is highest for airborne units, followed by infantry and armored units. The findings are consistent with armor having the highest combat effectiveness, followed by infantry, and finally by airborne; however, the results are also consistent with task difficulty being the lowest for armor and the highest for airborne.

Notably, we see little effect of the decrease in armored division resources on progress or KIA. Although this could indicate that the change in troop and tank levels had no effect on usefulness in combat, it is also consistent with simultaneous declines in the armored division's usefulness in combat and the difficulty of tasks assigned to it. We see little effect of the infantry reorganization on progress or KIA during days of combat, which is unsurprising, given that the reorganization had little effect on the infantry division's resources. For the airborne division the 1943-1944 reorganization is associated with a slight decline in progress and a large decline in KIA. This is consistent with a decline in usage intensity of the airborne division and either an increase in combat effectiveness or a decrease in task difficulty.

**IV. Model**

We now present the conceptual framework to guide us in investigating observed differences among division types in costs, success, and fatalities and the implied government's valuation of soldiers' lives. The cost function model used here is adapted from Rohlfs (2006a). Consider a country (or government) waging a war with $M$ total missions or campaigns. For each mission $m$, the government observes a vector $\mathbf{x_m^g}$ of pre-determined correlates of task difficulty and selects one of $S$ unit organizational structures $s_m$ and a usage intensity level $\imath_m$. For simplicity let the production functions for mission success $Y_m$ and own fatalities $F_m$ be the linear functions

(1) $Y_m = \alpha_{s_m}^Y + \alpha_\imath^Y * \imath_m + \mathbf{x_m^g}'\boldsymbol{\beta}^\mathbf{Y} + \varepsilon_m^Y$, and

(2) $F_m = \alpha_{s_m}^F + \alpha_\imath^F * \imath_m + \mathbf{x_m^g}'\boldsymbol{\beta}^\mathbf{F} + \varepsilon_m^F$,

where $\alpha_{s_m}^Y$ and $\alpha_{s_m}^F$ are constant terms that are specific to organizational structure $s_m$, and $\varepsilon_m^Y$ and $\varepsilon_m^F$ are error terms representing unobserved determinants of difficulty.

Organizational structure helps determine usage intensity, which the researcher does not observe. Let $\imath_m = \gamma_{s_m} + \mathbf{x_m^g}'\boldsymbol{\beta}^{\imath}$ denote the usage intensity that the country would select for structure $s_m$ and vector $\mathbf{x_m^g}$, a function that we take as linear. Suppose that $\mathbf{x_m^g}$ can be partitioned into vectors $\mathbf{x_m^o}$ and $\mathbf{x_m^u}$, where the researcher observes $\mathbf{x_m^o}$. Substituting, we obtain

(1') $Y_m = \alpha_{s_m}^{*Y} + \mathbf{x_m^o}'\boldsymbol{\beta}^{*\mathbf{oY}} + \varepsilon_m^{*Y}$, and

(2') $F_m = \alpha_{s_m}^{*F} + \mathbf{x_m^o}'\boldsymbol{\beta}^{*\mathbf{oF}} + \varepsilon_m^{*F}$,

where $\boldsymbol{\beta}^{A\prime} = [\boldsymbol{\beta}^{\mathbf{o}A\prime} \quad \boldsymbol{\beta}^{\mathbf{u}A\prime}]$ for each $A \in \{\imath, F, Y\}$, $\alpha_{s_m}^{*A} = \alpha_{s_m}^{A} + \alpha_{\imath}^{A} * \gamma_{s_m}$, $\boldsymbol{\beta}^{*\mathbf{o}A} = \boldsymbol{\beta}^{\mathbf{o}\imath} + \boldsymbol{\beta}^{\mathbf{o}A}$, and $\varepsilon_m^{*A} = \alpha_{\imath}^{A} * \mathbf{x_m^u}'\boldsymbol{\beta}^{\mathbf{u}\imath} + \mathbf{x_m^u}'\boldsymbol{\beta}^{\mathbf{u}A} + \varepsilon_m^{A}$ for $A \in \{F, Y\}$. The coefficients $\alpha_{s_m}^{*Y}$ and $\alpha_{s_m}^{*F}$ can be interpreted as the reduced-form effects of a change in organizational structure that include the direct effects of the physical inputs and the indirect effects of changing usage intensity.[7]

The government's/military's utility here increases with $Y_m$ and decreases with $F_m$ and dollar costs $C_m$. It is convenient in the current setting to consider expected costs given expected levels of mission success and fatalities:

(3) $E\left[C_m|\bar{Y}, \bar{F}, \mathbf{x_m^g}\right] = E\left[C_m|\mathbf{x_m^g}\right]$ such that $E\left[Y_m|\mathbf{x_m^g}\right] \geq \bar{Y}$ and $E\left[F_m|\mathbf{x_m^g}\right] \geq \bar{F}$.

Let $\tilde{C}_m\left(\bar{Y}, \bar{F}, \mathbf{x_m^g}\right)$ denote the expected expenditure required to obtain expected threshold levels $\bar{Y}$ and $\bar{F}$ of success and own fatalities. The total cost equation is analogous to the cost function in a producer's problem that depends on prices and output. Although wages and capital prices do not vary across missions the vector $\mathbf{x_m^g}$ of correlates of task difficulty plays a similar role as prices. Mission success and fatalities can be viewed as two different products whose output levels enter into the government's objective function. Let $P_m$ and $V$ equal the marginal values to the

[7] Strictly speaking, because the two production functions are initially simplified to be linear the subsequent cost function will also be linear so that the two marginal costs are constants, and there is no unique dual outcome cost minimum. The consequence is that the levels of mission success and fatalities will be determined by their marginal values to the military decision maker. We explore possible non-linear cost functions empirically in Section V.

government of a unit of expected success and a unit reduction in expected fatalities. $V$ is the parameter of our empirical interest and is assumed constant across missions. The first-order conditions of the military's optimization are $P_m = E\left[\frac{\partial \tilde{C}_m(\bar{Y},\bar{F},\mathbf{x_m^g})}{\partial \bar{Y}}\right]$ and $V = -E\left[\frac{\partial \tilde{C}_m(\bar{Y},\bar{F},\mathbf{x_m^g})}{\partial \bar{F}}\right]$.

$\tilde{C}_m(.,.,.)$ is linear here and is then

$$(4)\ \tilde{C}_m = P_m * E\left[Y_m|\mathbf{x_m^g}\right] - V * E\left[F_m|\mathbf{x_m^g}\right] + \mathbf{x_m^g}'\boldsymbol{\beta}^{\tilde{C}} + \varepsilon_m^{\tilde{C}},$$

where $\boldsymbol{\beta}^{\tilde{C}\prime} = \left[\boldsymbol{\beta}^{\mathbf{o}\tilde{C}\prime} \quad \boldsymbol{\beta}^{\mathbf{u}\tilde{C}\prime}\right]$. Neither $E\left[Y_m|\mathbf{x_m^g}\right]$ nor $E\left[F_m|\mathbf{x_m^g}\right]$ is observed by the researcher; however, substituting Equations (1') and (2') into Equation (4), we obtain:

$$(4')\ \tilde{C}_m = \bar{P} * Y_m - V * F_m + \mathbf{x_m^o}'\boldsymbol{\beta}^{\mathbf{o}\tilde{C}} + \varepsilon_m^{*\tilde{C}},$$

where $\bar{P} = \frac{1}{M}\sum_{m=1}^{M} P_m$ and $\varepsilon_m^{*\tilde{C}} = (P_m - \bar{P}) * Y_m + \mathbf{x_m^u}'\boldsymbol{\beta}^{\mathbf{u}\tilde{C}} + \varepsilon_m^{\tilde{C}} - P_m * \varepsilon_m^Y + V * \varepsilon_m^F$. Note that we do not allow usage intensity $\imath_m$ to affect costs directly,which may lead to an upward bias in the estimation of $V$; however, the bias is probably not very large.[8]

Both $Y_m$ and $F_m$ are endogenous variables that are correlated with components of $\varepsilon_m^{*\tilde{C}}$, such as $P_m$, $\varepsilon_m^Y$, and $\varepsilon_m^F$. Hence, $V$ cannot be consistently estimated with an Ordinary Least Squares (OLS) regression of Equation (4').[9] Instead we use a Two-Stage Least Squares (2SLS) strategy in which $Y_m$ and $F_m$ are endogenous regressors whose values are predicted using equations (1') and (2') as first-stage regressions with indicators for the different organizational structures as excluded instruments.

[8] Higher levels of $\imath_m$ probably led to higher ammunition costs and capital losses. However, the cost data take into account differences across division types in ammunition usage and tank losses; hence, the cost differences will be reflected in the comparisons across division types. Depreciation of capital other than tanks was a relatively minor cost, making up only 3 per cent and 4 per cent of the costs of the 1942 standard infantry and armored divisions. Hence, the largest differences in equipment losses among division types are accounted for in our regressions.

[9] In particular, OLS estimates of the marginal costs of mission success and fatality reductions will be biased toward zero because shocks to the cost structure will lead to choosing fewer, shorter missions (less success) and fewer soldier safety measures (more fatalities) if the two outcomes are endogenous in (4').

For the coefficients in Equation (4') to have a structural interpretation, it is essential that organizational structure $s_m$ is a choice variable that is endogenous to the model. Thus, the estimation strategy proposed here uses instruments that are not exogenous. Instead, we impose the weaker assumption of conditional exogeneity that, after controlling for $\mathbf{x_m^o}$, the organizational structure indicators are uncorrelated with unobserved determinants of task difficulty, and $P_m$, the importance of the mission. Hence, none of the division types can have been used more than others in tasks that were especially difficult in some unobservable way.

The main defense for imposing the conditional exogeneity assumption is that both the division by day panel and the engagement data include many control variables, among them detailed descriptors of enemy characteristics. Additionally, the sequential nature of the geographic targets limited the degree to which the Army could pick certain division types for certain tasks. Although Army doctrine recommended using each division type for a specific type of task, the main differences across tasks were the numbers and types of nearby ally and enemy units, factors that appear in $\mathbf{x_m^o}$. Some of our econometric specifications focus on within-division variation in organizational structure and control for U.S. division fixed effects, an approach that provides an even stronger way to control for battlefield strategy effects. Nevertheless, we note that the need for control variables and the possibility that the controls are incomplete represent limitations to our study.

One advantage of the 2SLS procedure here is that it combines the results from multiple margins of adjustment into a single measure of the rate at which the government made tradeoffs between dollars and U.S. fatalities. The procedure also has the unfortunate feature that it lacks transparency. To address improve transparency, we present the first-stage and reduced-form regressions in graphical form to illustrate the separate roles of each of the division types in the final estimates, and we present the 2SLS results separately for different sets of divisions.[10]

A. Strategy and Endogenous Enemy Characteristics

We include enemy units' characteristics in the set of controls, but the model does not allow enemy units' characteristics to respond to the U.S. unit's division type or usage intensity. For the division by day panel, the enemy unit assumption is probably reasonable. The division by day panel dataset's controls for enemy characteristics come from information on long-range movements. The measures of enemy locations probably responded to large-scale events such as the success of the overall war effort; however, they are too coarse to detect responses to a single U.S. unit's division type.

In the engagement data the controls for enemy characteristics include enemy troops, tanks, aerial sorties, and in some cases, Axis division fixed effects. At the division level, attacking units had the ability to choose their opponents; however, the U.S. was the attacker in 90 per cent of the combat days considered. The primary way that a defending force could respond is through retreat or withdrawal, actions that are treated as endogenous and are not included in the controls. So, for a given engagement it is not unreasonable to assume that the U.S. treated the German force's starting troop and tank levels as fixed quantities that did not

[10] The focus of our 2SLS approach is not the variation in the dependent variable but instead as a way to combine the various reduced-form coefficients into a summary measure of cost per life saved. In the just identified case where the sample includes only three division types and only two organizational structure indicators appear in the set of excluded instruments, the 2SLS procedure here is identical to measuring the effects of a weighted sum of the two policies (switching from type one to type two and partially switching from type two to type three), where the second policy is implemented in the exact proportion necessary to hold mission accomplishment constant. In our context, $V$ is the estimated effect of the weighted sum of policies on dollar costs divided by the effect on fatalities. (See Rohlfs (2006b) and the available appendix.)

respond to the attacking unit's division type.[11] German troops and tanks may have responded to American organizational structure for the one per cent of cases in which the German unit was the attacker, and German air sorties may have responded in the 17 per cent of cases in which there was German air support. Dropping observations with possible German responses to U.S. actions has little effect on the estimates, as does dropping the Axis inputs from the set of controls (results shown in the available appendix).

In some cases, a unit's actions in one engagement could generate benefits to other engagements. For instance, a U.S. unit's success could reduce the task difficulty for the next Allied unit facing the same enemy. In the current framework the government's value $P_m$ of the mission meters subsequent benefits to other U.S. units. Treating enemy characteristics as pre-determined correlates of task difficulty in $\mathbf{x_m^o}$ helps to avoid double-counting of benefits in other engagements.

B. Spillover Effects of Nearby Units

Because multiple divisions usually traveled together as a corps, a given Allied division probably had spillover effects on the geographical progress of other nearby Allied divisions. The main specifications address spillover effects by including the numbers of nearby divisions of different types as control variables in the regressions. Hence, the benefits of the positive spillovers generated by a unit, while valued by the country, are not counted in the mission effectiveness of the unit. An alternative formulation that takes benefits into account is to model progress as a corps-by-day level phenomenon and to estimate Equation (4') at the higher level of

[11] Troop and tank levels in the engagement data measure the military strengths at the start of each engagement. If significant reinforcements arrived, the data treat this as two engagements, one before the reinforcements arrived and one after the reinforcements arrived (Dupuy, 1987, pg. 65).

aggregation. Estimates using the corps level approach appear in the available appendix and, while less precise, yield generally similar results to results presented.

C. Troop and Tank Regressions

One alternative formulation of the first-stage equations used in some of the specifications replaces the organizational structure indicators with continuous regressors measuring the numbers of troops and tanks of the U.S. unit together with their interaction. Implementing the troop-tank interaction approach involves the following substitutions into Equations (1') and (2'):

(5) $\alpha_{s_m}^{*A} = \alpha_{Troops}^{*A} * Troops_m + \alpha_{Tanks}^{*A} * Tanks_m + \alpha_{TT}^{*A} * Troops_m * Tanks_m,$

for $A \in \{F, Y\}$. The approach summarized in (5) is in some formulations involving the engagement data, for which there are direct measures of U.S. troops and tanks, and it is the one used by Rohlfs (2006a, 2006b). The procedure has the disadvantages that many of the cross-sectional differences in U.S. troops and tanks reflect differences in attachments or detachments (which the Army could change quickly depending on the needs of a given mission) or recent combat losses, increasing the likelihood that the differences are caused by unobserved determinants of mission difficulty. The equation (5) approach has the advantage, however, that it can be implemented with U.S. and Axis division fixed effects together with the full set of controls from the engagement data.

## V. Empirical Results

We now present our main empirical findings. First, we show estimates from Equations (1') and (2') in such a way as to illustrate how the estimated cost per life saved varies across different policies and regression specifications. Due to the large number of pre- and post-reorganization division types and the complex interactions between combat effectiveness and usage intensity, the first-stage regressions of Equations (1') and (2') are cumbersome to present in tabular form. So, for simplicity the first-stage estimates appear graphically in Figure 3. The corresponding regression tables appear in the available appendix.

A. Graphical Summaries

In Figure 3 the variables that we treat as exogenous are division type (Armored, Infantry, or Airborne) and pre-post reorganization during 1943-1944. The combination of the two organization variables sorts the data into six or fewer distinct groups, depending upon data availability, which varies across the graphs shown. Each of the unit types had a certain cost, a certain rate of fatalities, and a certain level of mission accomplishment, which vary by model and which explain the existence of the eight different graphs.

The axes of the graphs in Figure 3 show only two dimensions, cost and fatalities, which we plot along the vertical and horizontal axes,. To illustrate the third dimension, mission success, in a way that is easily identifiable for readers, we plot the dashed isoquant curves shown. The curves are hand-drawn -- they are not the result of an estimation process -- and they are generated to be consistent with the ordering of the mission accomplishment levels achieved by the different unit types shown on the graph. Each of the resulting curves is the simplest, smoothest one that we could draw given the ordering of mission accomplishment levels observed in the data across the six or fewer points.

Within each of the eight panels in Figure 3 the estimated dollar cost of a 10.8-month deployment of that division type appears on the vertical axis. The cost estimates are the same as in Figure 1. We use the European Theater of Operations (ETO) costs in panels A through D and

G and H.[12] The costs for the actual troop and tank levels appearing in panels E and F are also the same as in Figure 1. The estimated number of fatalities that the division would incur over that 10.8 months appears on the horizontal axis. The average levels of mission success as shown in the isoquants are predicted values by division type from Equation (1'), where the control variables are set equal to the averages over the sample being used. The isoquants show alternative combinations of dollar costs and U.S. fatalities that generate equivalent levels of mission effectiveness. Division types on the upper left of the graph were expensive in dollars but experienced few fatalities. Moving downward and to the right along an isoquant the dollar cost of the unit decreases. To maintain the same level of effectiveness, usage intensity increases, leading to higher numbers of fatalities. The slope of the curve is an estimate of the rate of tradeoff between expenditures and fatalities. In some cases, the curves could be steeper or flatter and still agree with the observed levels of success; however, the range of possible slopes is fairly narrow at many key points on the graphs.

Although the slopes of the isoquants in Figure 3 are not the result of a formal estimation process the placement of the different points in terms of cost, fatalities, and mission accomplishment is surprisingly restrictive in terms of what the isoquants might look like. In panels A, B, and C, for instance, any isoquant that is consistent with the data must have a steep portion in the upper left part of the graph (to match the ordering of the two black points) and a flat portion in the lower right-hand part (to match the ordering of the two gray points).

To estimate fatalities we first computed predicted values from Equation (2'), where U.S. KIA is the dependent variable and the control variables are set to their sample averages. For the regressions using the division by day panel, total estimated KIA for a 10.8-month deployment

[12] The estimated cost for pre-reorganization infantry, which is missing in Figure 1, assumes that the percentage change in costs generated by the infantry reorganization was the same as in the engagement data. Additional information on the ETO costs presented in Figure 3 appears in the available appendix.

comes from multiplying predicted KIA per combat day by the average division's number of combat days and dividing by the fraction of U.S. KIA that occurred on the combat days. To convert from KIA to fatalities, we divided the 10.8-month KIA totals by 0.84, the fraction of U.S. deaths that were KIA. Hence, a division type's fatalities over the deployment are taken as proportional to KIA for that division type on an average combat day.

Panels A through D show results from the division by day longitudinal data; panels A and B use the sample of division days with nearby Axis divisions, and panels C and D use the sample of division days with five or more U.S. KIA. Panels E through H show results from the engagement data. In panels G and H, the averages by division type use the coefficients from the troop and tank regressions, substituting in the average troop and tank numbers from the ETO data. The measure of mission success is km progress in panels A through D and the index of mission accomplishment in panels E through H. Panels A, C, E, and G use no control variables. Hence, for panels A, C, and E, the fatalities estimates are scaled versions of the KIA averages shown in Figures 1 and 2, and the mission effectiveness estimates used to generate the dashed lines are also taken from Figures 1 and 2. Panels B and D show conditional means estimated from regressions that control for date and continent, numbers of nearby Allied and Axis divisions, terrain, vegetation, weather, and combat experience; panels F and H control for date and continent, U.S. aerial sorties, enemy inputs, terrain, vegetation, weather, and human factors. The control variables just described are listed in the footnotes to Tables 1 and 2.

When the data are sufficiently informative in Figure 3 to determine the cost per life saved, as measured by the slope of the isoquant, it tends to be highest at the higher cost levels, with a generally steeper tradeoff than the efficient rate of $1 million to $2 million dollars per life. At the lower cost levels the cost per life saved tends to be lowest and flatter than the efficient rate just mentioned. In each of panels A, C, and E, dollar costs are highest for the armored divisions, and fatalities are highest for the airborne divisions. The isoquants are roughly convex in all three panels, with kinks around the middle expenditure levels in panels A and E and a backward-bending portion for the armored divisions in panel C. At the highest two cost levels in panel A, the average slope between the cost levels of the pre- and post-reorganization armored divisions on the highest isoquant is about –$3 million per life. On the same isoquant in panel A the slope between the lowest cost levels of the pre- and post-reorganization airborne divisions is approximately –$0.5 million per life. On the highest isoquant drawn on panel C, the slope between the cost levels of the pre- and post-reorganization armored divisions is roughly +$2 million per life. The curve flattens to about –$1 million per life between the cost level of the post-reorganization armored and the fatality level of the infantry division. Although the slope is unclear at lower cost levels the curve is necessarily flatter than the roughly –$0.9 million per life slope between the infantry divisions and the post-reorganization airborne division, which is on a lower isoquant. On the highest isoquant in panel E, the average slope between the cost level of the pre-reorganization armored division and the fatality level of the post-reorganization airborne division is about –$0.7 million per life. When the troop and tank regressions are used in panel G, many slopes are possible, and the data are fairly uninformative about the tradeoffs between expenditures and U.S. fatalities.

When we add controls to the regression for the sample with nearby Axis divisions in panel B, the slope steepens. On the second-highest isoquant in panel B the average slope between the cost levels of the pre- and post-reorganization armored divisions is about –$6 million per life. On the highest isoquant in panel B the average slope between the fatality levels of the pre-reorganization armored and the post-reorganization airborne divisions is about –$1 million per life. For the sample of division days with five or more U.S. KIA, adding controls in panel D generates isoquants that are not consistent with a government that values mission success. When controls are added to the engagement data in panels F and H, we observe relatively flat slopes. In panels F and H the slopes of the isoquants between the fatality levels of the pre-reorganization armored and the pre-reorganization infantry divisions are not explicitly determined but are necessarily less than –\$0.4 million and –\$0.6 million per life, respectively.

B. Regression Results

Before presenting our cost function regression estimates it is important to emphasize the relative advantages of the two different data sets we use. The benefit of the engagement data is the quality of the measurements. Everything comes from detailed first-hand accounts, and we know how many people were on the battlefield on both sides, how much equipment they had, how many died, and we have a good metric for mission accomplishment. The downsides of the engagement-level data are selection bias and omitted variables bias – we only observe battles that were big enough to matter for U.S. divisions that were important in the war effort, and we don't have strong instruments for troop and tank use so we are left assuming that they are exogenous.

The benefits of the division-level data are exactly where the engagement-level data are lacking. We have instruments for troop and tank numbers (the reorganization policy), and we have a large and complete sample of all the engagements between U.S. and Axis forces. The disadvantages are the quality of the measurements. We have rough measures of U.S. division movements, which involve interpolations to estimate where each division was (and consequently distance moved, terrain, weather, and locations of enemy forces). Counting numbers of fatalities involves matching individual soldiers to dates of death, which are missing for some individuals and has some inconsistencies. However, the main measurement error problems in the division-level data should be mitigated by the instrumental variables approach we use because the most important sources of measurement errors are in the endogenous variables. Finally, the value that the government placed on soldiers' lives is best estimated by looking at the full sample of fatalities in the division level data and not in the most important and high-profile engagements.

In addition to presenting in Tables 1 and 2 our cost function parameter estimates of the marginal costs of the two endogenous variables, mission success and soldiers' fatalities, we tabulate typical accompanying indicators of the models' instrument strengths and the degree with which the models' identifying instruments may be considered exogenous.[13] Considering instrument strength, there is no unique critical value for the partial *F* statistics for the excluded (identifying) instruments, rather a guiding principle that a higher *F* is better (Angrist and Pischke 2009). However, as Greene (2012, p. 250) notes, the instrument strength check is neither a specification test nor is it a constructive test for model building, but instead a strategy that helps the researcher avoid possibly basing inference on unreliable statistics. Concerning whether the overidentifying restrictions are valid, we also note that lower Chi squares are better. However, formal overidentifying restrictions tests can be misleading because the empirical validity of the overidentifying restrictions is neither sufficient nor necessary for the validity of the moment conditions implied by the underlying model and in turn provide little or no information on the identification of parameters of interest (Deaton 2010, Parente and Santos Silva 2012).

We now turn to our 2SLS estimates of $\bar{P}$ and $V$ from Equation (4').

[13] We do not tabulate Hausman-Wu statistics of endogeneity of *Y* and *F* because our results uniformly reject exogeneity (equality of OLS and 2SLS estimates of the marginal costs in (4')). See footnote 14 for a numerical example of the difference.

*Division Data Results*. Table 1 shows the 2SLS results for the division by day longitudinal data set. Within each of the two panels in the Table, a column shows results from a distinct 2SLS regression of Equation (4'), where the dependent variable is cost per combat day, the endogenous regressors are geographic progress and U.S. fatalities, and the excluded instruments are indicators for the different pre- and post-reorganization division types.[14] To construct daily fatalities, we divide U.S. KIA by the product of the fraction of U.S. KIA that occurred on combat days and the fraction of U.S. fatalities that were KIA. The coefficient on progress can be interpreted as the U.S. government's valuation (marginal cost) of one km of progress in a typical combat day, and the coefficient on U.S. fatalities can be interpreted as negative one times the U.S. government's valuation (marginal cost) of one fatality reduction.[15]

In panel A of Table 1, the sample includes division days in which the U.S. division was in the same cell as one or more Axis divisions; in panel B, the sample includes division days in which U.S. KIA was five or more. The first three columns show results from the full sample of combat days, and columns (4) and (5) present results from the fixed effects samples. Column (1) shows results controlling for a time trend and continent fixed effects. Column (2) includes the full set of additional controls, and columns (3) and (4) add fixed effects for month x year, nearby Axis divisions, and 0.25 x 0.25-coordinate geographic cells. Relative to Figure 3, the regressions in columns (1) to (4) of Table 1 impose a constant slope on the isoquants and constant growth in mission effectiveness per dollar of expenditure from one isoquant to another. The regressions in column (5) control for U.S. division fixed effects, so that the indicators for armored and airborne

[14] As an indication of bias from ignoring endogeneity of $Y$ and $F$ in (4') their coefficients each shrink by 99 percent in absolute value if we use OLS to estimate the first regression in Table 1, for example.
[15] As noted earlier the basic estimating equation is linear in $F$ and $Y$ so that there are constant marginal costs. We explored the empirical validity of the linear cost function in (4') by including endogenous quadratics in progress and fatalities ($Y^2$ and $F^2$) or by including an endogenous interaction term ($Y \bullet F$) with no empirical success in finding non-constant marginal costs.

appear in the controls and the coefficients of interest are identified from variation generated by the reorganizations. The remaining columns of Table 1 apply varying restrictions to the sample so that different combinations of the instruments identify the coefficients of interest. In each case the regressions that controls for continent and a daily time trend are in the first column, while regressions with controls for month x year, Axis divisions, and cell fixed effects are in subsequent columns. We use standard errors clustered by U.S. division by year by month interaction, which are in parentheses (Cameron and Miller 2015).[16]

In columns (1) to (4) of Table 1 the coefficients on km progress are unstable and change signs across specifications in both panels. Hence, we do not find a consistent positive marginal cost of increasing mission success, possibly due to the combined imprecision of the first-stage progress measure and the linear specification. The U.S. fatality coefficients in columns (1), (2), (3), and (4) in panel A are -1.436, -1.926, -0.476, and -0.408. All four fatality coefficients are more than twice the value of their standard errors, respectively. This is in contrast to the first four columns in panel B, where only the U.S. fatality coefficient in column (3) is more than 1.68 times larger than its standard error. In columns (1), (2), (3), and (4) of panel B the fatality coefficients are -0.711, -4.673, -2.521, and -3.197. Thus, the marginal cost per life saved estimates in columns (1) to (4) in panels A and B range in value from $0.41 million to $2.5 million, with average and median estimates of $1.9 million and $1.7 million per life. The larger estimates are from regressions with negative coefficients on km progress, a result suggesting that the regressions with the higher cost per life saved do not adequately control for the mission effectiveness of the unit.

[16] The standard errors do not take into account any imprecision in the constructed dollar cost measures. Some serial correlation also probably exists between divisions and between days from different months. The smaller clusters used make the model estimable with the full set of controls and fixed effects. When we use fewer covariates, using fewer clusters in both datasets has little effect on the standard errors, as shown in the available appendix.

When we add U.S. division fixed effects, as in the regressions in column (5), the coefficient on progress is positive in panel A and zero in panel B, and the estimated costs per life saved are \$0.3 million and \$0.4 million. With the sample restrictions applied in columns (6) to (15), the coefficients on U.S. fatalities are negative in 18, more than twice the value of their standard errors in four, and more than 1.68 times larger (but less than two times larger) than the value of their standard errors in three of the 20 specifications. The estimated cost per life saved tends to be larger in panel B, with average and median values of \$2.8 million and \$1.3 million, than in panel A, with average and median values of \$1.3 million and \$1.2 million. The coefficient on km progress tends to be positive in the sample with nearby Axis divisions in panel A and negative in the sample with five or more U.S. KIA in panel B; hence, the larger estimated cost per life saved in panel B is probably attributable to the regressions failing to adequately control for the policies' effects on mission accomplishment. When considering tradeoffs between armored and either of the other two division types the cost per life saved estimates in panel A range from \$0.5 million to \$1.5 million. The estimated cost per life saved is considerably lower, ranging from zero to \$0.3 million, when the sample is restricted to infantry and airborne divisions, and the coefficient on km progress is negative in three out of four specifications. In columns (12) to (15), we find comparable cost per life saved estimates pre- and post-reorganization. The cost per life saved estimates are also generally smaller in the specifications that include the month by year, Axis division, and geographic cell fixed effects.

*Engagement Data Results.* Table 2 shows 2SLS estimates of Equation (4') from the engagement data. In panel A, mission success is km of progress along the attacker's axis of advance, and in panel B, mission success uses the subjective index. Within each panel, each column shows results from a different regression specification. In columns (1) through (5) the sample excludes the airborne observations, and the excluded instruments are three indicators for division type (armored, post-reorganization times armored, and post-reorganization times infantry).[17] In columns (6) to (15), the excluded instruments are U.S. troops, U.S. tanks, and their interaction.

The coefficient on mission effectiveness is more consistently positive in Table 2 than in Table 1, probably due to the greater precision of the effectiveness measures in the engagement data. The specifications that use the success index in panel B have the most consistently positive and precisely estimated coefficients on mission effectiveness, a result that suggests that the specifications more effectively control for mission success than do the specifications in panel A. The coefficients on the success index is positive in 14, more than twice their respective standard errors in six, and more than 1.68 times larger (but less than two times larger) than their standard errors in three of the specifications. The coefficient on km progress tends to be larger in Table 2 than in Table 1, because the engagement sample includes fewer combat days, and unlike U.S. fatalities the mission success measures are not scaled upward to count progress made on non-combat days. Among the specifications using division type as the excluded instruments in columns (1) to (5), the coefficient on U.S. fatalities is positive in the two specifications without additional controls beyond date and continent and is negative in the remaining eight specifications. Among the specifications with the additional controls, the cost per life saved estimates range from \$0.1 million to \$1.9 million. The specifications with all of the controls produce estimates of \$0.4 million to \$0.6 million per life saved, with both coefficients being more than twice the values of their respective standard errors.

[17] We exclude the 10 combat days of the 101st Airborne Division in Bastogne in December 1944 from the sample due to high numbers of attached troops and tanks that made them unrepresentative of a typical airborne organization.

When U.S. troops and tanks and their interaction are the instruments (columns (6) to (15)), the specifications are also sensitive to the inclusion of controls. When we include controls beyond date and continent, and when km progress is the measure of success in panel A, we obtain a small positive coefficient on U.S. fatalities in the sample with low tank-intensity and negative coefficients on U.S. fatalities in the full sample and in the sample with high-tank intensity. However, the specifications with negative coefficients on U.S. fatalities also produce negative coefficients for km progress, suggesting that the specifications in columns (6)-(15) of panel A also do not adequately control for mission effectiveness. In the corresponding specifications in panel B, we observe a consistently positive coefficient on mission success and estimated costs per life saved of $1.2 million for the full sample, –$0.1 million for the low tank intensity sample, and $0.4 million for the high tank intensity sample (which includes some units around the tank-intensity level of the infantry division), which are results generally consistent with panel A of Table 1. Similar results appear for the fixed effects sample as for the full sample; however, the results become too imprecise to make inferences when we add fixed effects to the regressions in columns (14) and (15).

After taking into account placing value on soldiers' lives, our estimates from the mission effectiveness data suggest that the U.S. government initially appeared to value armored troops' lives more than those of infantry troops. Although the cost/value discrepancy between soldiers existed initially, the government seems to have regarded that decision as a mistake and reorganized the divisions in 1943. The reorganization largely corrected the discrepancy in the valuation of soldiers' lives between the armored and infantry units. An additional explanation for the difference in the two estimates is that soldiers in armored divisions had more human capital than soldiers in infantry divisions. Although we believe that some of the difference in the evaluation of troops lives is due to differences in training expenditures, which we measure, we interpret other differences as due to soldiers in armored divisions having more experience and higher quality experience than infantry soldiers.

## VI. Conclusion

Our study has examined tradeoffs that the U.S. government made among different types of military units so as to save soldiers' lives in WWII. Multiple data sources let us measure physical inputs, fatalities, geographical characteristics, and dollar expenditures of each unit, including new data compiled from archival sources on the experiences of all 67 U.S. divisions that fought on the Western Front. We examined the effects of substitution among three different types of units -- armored, infantry, and airborne divisions -- as well as the effects of mid-war reorganizations of each unit type. The conceptual framework presented guided us in understanding the interactions among the physical inputs of the unit, the intensity with which the unit was used, and the difficulty of tasks to which it was assigned. We also developed a procedure for estimating the marginal cost of reducing U.S. fatalities through an increase in tank intensity. If the U.S. government acted as though it were an economically rational decision maker who equated marginal costs and marginal benefits then the estimated marginal cost provides a measure of the implicit value that the government placed on reducing American military deaths.

Although variable across specifications, our empirical results indicate that, at moderate tank-intensity levels such as that of the infantry division, the cost per life saved from an increase in tank intensity for a deployment with average usage and task difficulty was roughly zero to $0.5 million in 2009 dollars. The cost of life saving range falls below Costa and Kahn's (2004)

$1 million to $2 million estimate of the private valuation of risk reductions among young men in the 1940s. At relatively high tank-intensity levels, such as that of the armored division, the cost per life saved from an increase in tank intensity was roughly $2 million to $6 million or more in 2009 dollars. Thus, our results suggest that relative to the private value of citizens at the time the U.S. government implicitly undervalued infantrymen's lives and slightly overvalued armored personnel's lives. Both the 1943 reorganization of the armored division, which greatly reduced costs and slightly increased fatalities, and the 1944 reorganization of the airborne division, which greatly reduced fatalities and increased costs slightly, increased economic efficiency.

## References

Angrist, Joshua D. and Jörn-Steffen Pischke. 2009. *Mostly Harmless Econometrics, An Empiricist's Companion*. Princeton, NJ: Princeton University Press.

Axis History Fact book. 2009. "Military Organisations: Heer." Available at: http://www.axishistory.com/index.php?id=30

Cameron, A. Colin and Douglas L. Miller. 2015. "A practitioner's guide to cluster-robust inference." *J. of Human Resources, 50*(2), 317-72.

Costa, Dora and Matthew Kahn. 2004. "Changes in the value of life: 1940-1980." *J. Risk & Uncertainty*, *29*(2), 159-80.

Deaton, Angus. 2010. "Instruments, randomness, and learning about development." *J. of Econ. Lit.*, *48*(2), pp. 424-55.

Dupuy, Trevor N. 1987. *Understanding War*. New York: Paragon House Publishers.

The Dupuy Institute. 2005. "Appendix M: Representativeness of the DLEDB." Unpublished Paper.

The Dupuy Institute. 2001. *User Guides for the Dupuy Institute Databases*. Annandale, VA. September.

*Economist*. 2005. "And Now, the War Forecast." (September 17).

Evans, Martin Marix. 2002. *Battles of World War II*. Shrewsbury, England: Airlife Publishing, Ltd.

Fuller, Colonel J.F.C. 1928. *On Future Warfare*. London: Sifton Praed & Co., Ltd.

Gabel, Christopher R. 1985a. "Lorraine Campaign: An Overview, September-December 1944." Combat Studies Institute, United States Army Command and General Staff College.

Gabel, Christopher R. 1985b. "Seek, Strike, and Destroy: U.S. Army Tank Destroyer Doctrine in World War II." Leavenworth Papers No. 12, Combat Studies Institute, United States Army Command and General Staff College.

Gabel, Christopher R. 1986. "The 4th Armored Division in the Encirclement of Nancy." Combat Studies Institute. United States Army Command and General Staff College.

Greene, William H. 2012. *Econometric Analysis, Seventh Edition*. Upper Saddle River, NJ: Prentice Hall.

Greenfield, Kent R., Robert R. Palmer and Bell I. Wiley. 1947. *United States Army in World War II: The Army Ground Forces: The Organization of Ground Combat Troops*. Washington, DC: United States Army Center of Military History.

Greenstone, Michael, Stephen P. Ryan, and Michael Yankovich. 2014. "The Value of a Statistical Life: Evidence from Military Retention Incentives and Occupation-Specific Mortality." MIT Working Paper.

Harrison, Mark. 1988. "Resource Mobilization for World War II: The U.S.A., U.K., U.S.S.R., and Germany, 1938-1945." *Econ. Hist. Rev.*, New Series *41*(2): 171-92.

Haskew, Michael E. 2009. "Order of Battle Western Allied Forces of WWII." London: Amber Books, Ltd.

Kahn, Ely J. and McLemore, Henry. 1945. *Fighting Divisions*. Washington, DC: Zenger Publishing Co., Inc. (reprinted 1980).

Liddell Hart, Captain B.H. 1925. *Paris or The Future of War*. E.P. Dutton & Company. New York.

Morrall III, John F. 2003. "Saving lives: A review of the record." *J. Risk & Uncertainty 27*(3), 221-37.

Morris County Library, 2009. "Historic Prices, Morris County NJ." Available at: http://www.gti.net/mocolib1/prices/.

Palmer, Robert R., Bell I. Wiley, and William R. Keast. 1959. *United States Army in World War II: The Army Ground Forces: The Procurement and Training of Ground Combat Troops*. United States Army Center of Military History. Washington, DC. Reprinted 1991.

Parente, Paulo M.D.C and J.M.C. Santos Silva. 2012. “A cautionary note on tests of overidentifying restrictions.” *Econ. Letters 115*(2), 314-17.

Rohlfs, Chris. 2006a. “The Government’s Valuation of Life-Saving in War: A Cost Minimization Approach.” *Papers and Proceedings of the Amer. Econ. Assoc., 96*(2): 39-44 (May).

Rohlfs, Chris. 2006b. “Three Essays Measuring Dollar-Fatality Tradeoffs and Other Human Costs of War.” Ph.D. Dissertation, University of Chicago (June).

Rohlfs, Chris. 2012. “The economic cost of conscription and an upper bound on the value of a statistical life: Hedonic estimates from two margins of response to the Vietnam draft.” *J. Benefit- Cost Analysis 3*(3), 1-37.

Rohlfs, Chris and Ryan Sullivan. 2013. “The Cost-Effectiveness of Armored Tactical Wheeled Vehicles for Overseas U.S. Army Operations.” *Defence and Peace Economics*, *24* (4), 293-316.

Rosen, Sherwin and Richard Thaler. 1975. “The Value of Saving a Life: Evidence from the Labor Market,” in *Household Production and Consumption*, edited by Nestor E. Terleckyj, National Bureau of Economic Research. New York.

Rottman, Gordon L. 2006. *U.S. Airborne Units in the Mediterranean Theater 1942-44*. Oxford, United Kingdom: Osprey Press.

Stubbs, Mary Lee and Stanley Russell Connor. 1969. *Army Lineage Series: Armor-Cavalry Part I: Regular Army and Army Reserve*. Washington, DC: United States Government Printing Office.

Smith, R. Elberton. 1959. *United States Army in World War II: The War Department: The Army and Economic Mobilization.* United States Army Center of Military History. Washington, DC.

Stanton, Shelby. 1984. *Order of Battle: U.S. Army, World War II*. New York: Presido Press.

Steadman, Lieutenant Colonel Kenneth M. 1982. “The Evolution of the Tank in the US Army, 1919-1940.” Combat Studies Institute Report No. 1. Combat Studies Institute. United States Army Command and General Staff College. Fort Leavenworth, KS.

United States. Army Service Forces. 1942. “Army Supply Program: Section 1: Equipment, Ground.” Statistical Unit, April 6, 1942 (Box 704). Record Group 160, Entry 94. National Archives II Building, College Park, MD.

United States. Congress. 1932. Representative Collins speaking on War Department Appropriation Bill and resulting curtailment of Army activities. *Congressional Record*. 72nd Congress, 1st session, 1932, 75(9), daily ed. (May 10).

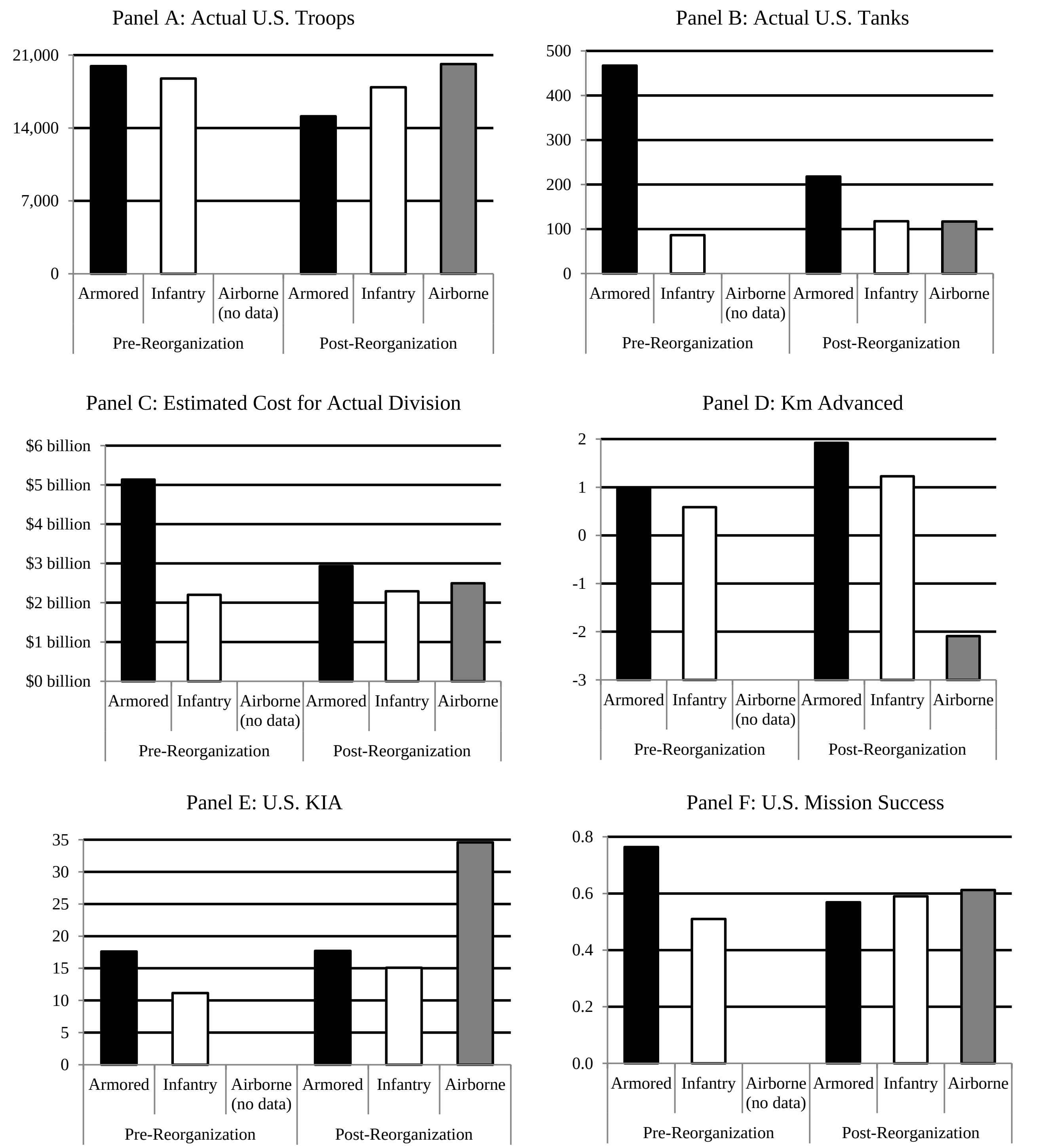
Viscusi, W. Kip. 1993. “The Value of Risks to Life and Health.” *J. Econ. Lit.*, 31 (December): 1912-46.
Viscusi, W. Kip. 1996. “Economic Foundations of the Current Regulatory Reform Efforts.” *J. Econ. Perspect*. 10 (Autumn): 119-34.

Watson, Mark Skinner. 1950. *United States Army in World War II: The War Department: Chief of Staff: Prewar Plans and Preparations*. United States Army Center of Military History. Washington, DC. Reprinted 1991.

Wilson, John B. 1998. *Maneuver and Firepower: The Evolution of Divisions and Separate Brigades*. United States Center of Military History. Washington, DC.

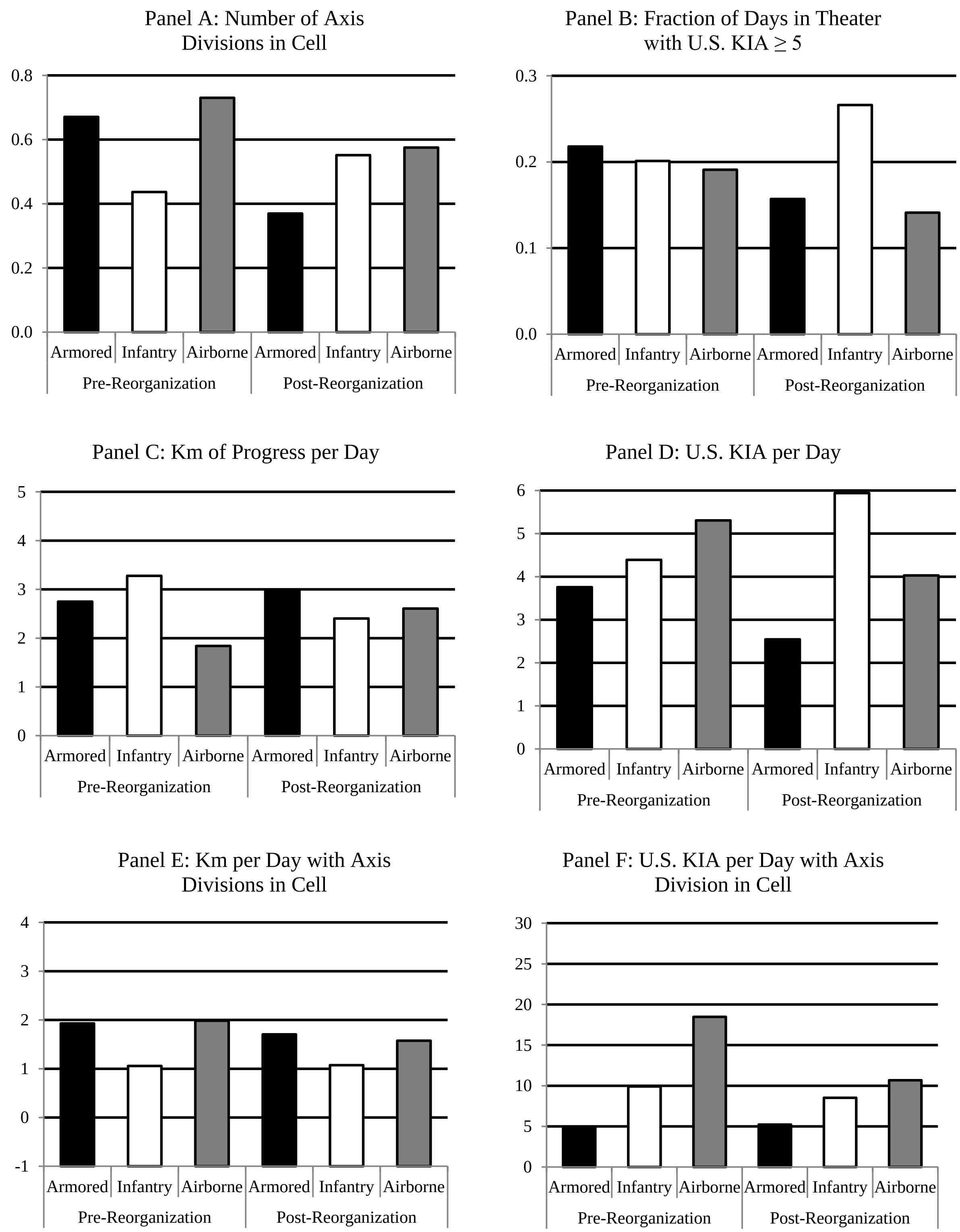
Zaloga, Steven J. 2007. *U.S. Airborne Divisions in the ETO 1944-45.* Oxford, United Kingdom: Osprey Press

Figure 1: U.S. Troops, Tanks, Estimated Cost, and Combat Outcomes by Division Type (Engagement Data)




Notes to Figure 1: Actual troops and tanks are taken from primary sources such as morning roll call counts. Costs measured as $92,400 per troop, $5.84 million per tank, and an additional $1.63 million per tank used in an armored division due to armored divisions' higher rates of tank losses. Estimated costs are in 2009 U.S. dollars. Mission success is measured as a zero to one index. Full sample is used and additional details are in the available appendix.

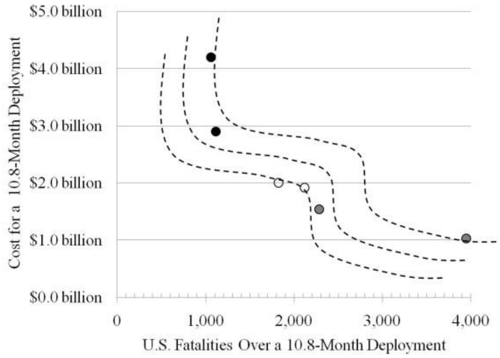
Figure 2: Combat Outcomes and Usage in Combat by Division Type (Division by Day Panel)



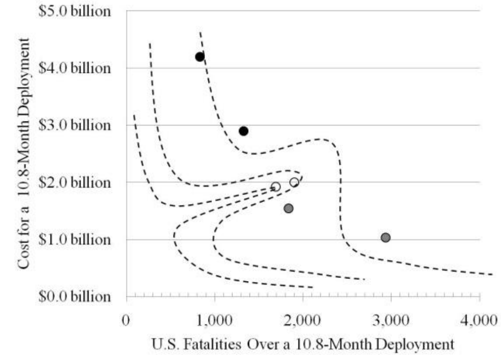

Notes to Figure 2: Data and variables are defined in the same way as in Table A1. Panels E and F show U.S. km of progress per day and U.S. KIA, respectively when the sample is restricted to observations in which one or more Axis divisions is in the same cell as the U.S. division.

Figure 3: Estimated Costs, Fatalities, and Military Production Isoquants by Division Type

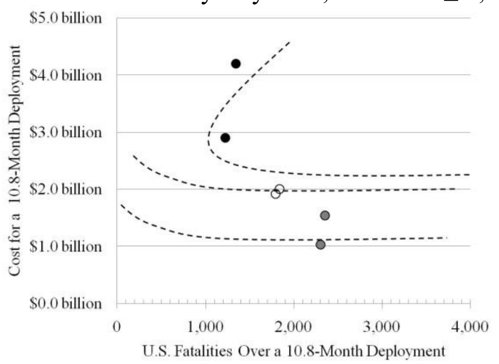
Panel A: Division by Day Data, Axis in Cell, No Controls



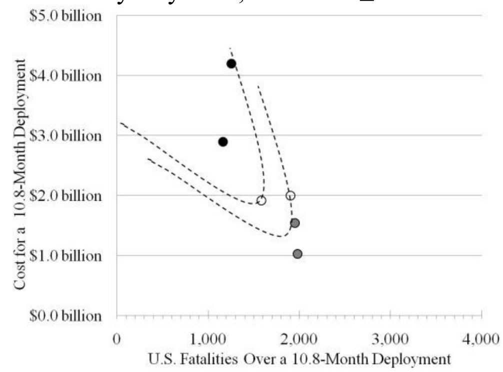

Panel B: Division by Day Data, Axis in Cell w/ Controls



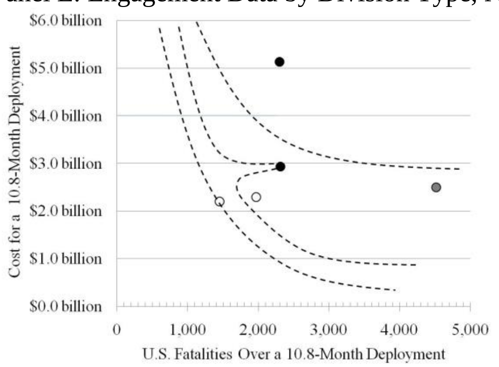

Panel C: Division by Day Data, U.S. KIA ≥ 5, No Controls



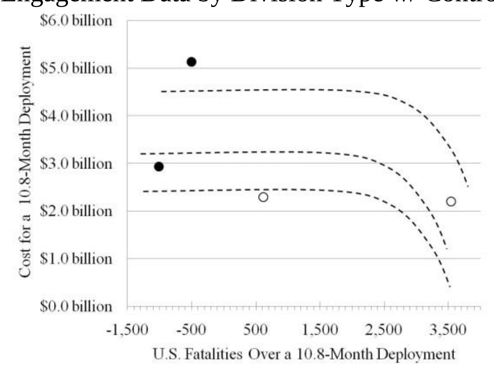

Panel D: Division by Day Data, U.S. KIA ≥ 5 w/ Controls



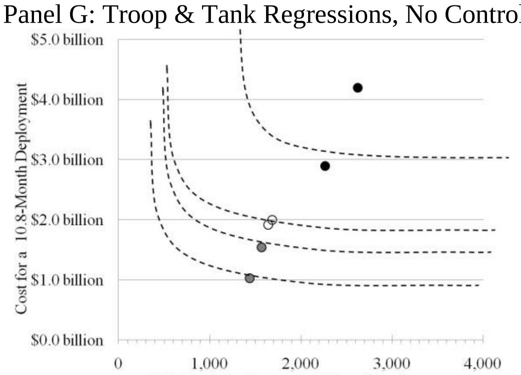

Panel E: Engagement Data by Division Type, No Controls



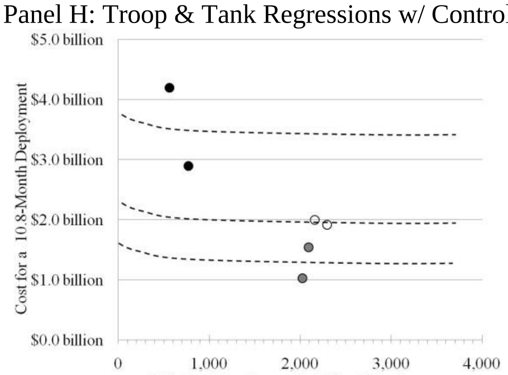

Panel F: Engagement Data by Division Type w/ Controls




Panel G: Troop & Tank Regressions, No Controls




Panel H: Troop & Tank Regressions w/ Controls




Notes to Figure 3: In each panel, the points show estimated costs and fatalities for a given division type over a 10.8-month deployment, assuming average usage. The black dots correspond to armored divisions, the white dots correspond to infantry divisions, and the gray dots correspond to airborne divisions; both pre- and post-reorganization means are shown. The dashed curves show hand-drawn isoquants for military effectiveness that are consistent with the estimated levels of effectiveness of each division type. Effectiveness in panels A to D is km advanced while engaged in panels E to H with the mission success index. All w/controls specifications include the full set of controls.

Table 1: 2SLS Estimates of the Cost Function for Military Operations, Division by Day Panel

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dependent Variable is Estimated Dollar Cost per Day in Millions of 2009 Dollars | | | | | | | | | | | | | | | |
| Panel A: Division Days in Which Axis Divisions in Cell ≥ 1 | | | | | | | | | | | | | | | |
| Excluded Instruments are Indicators for Armored, Airborne, Post-Reorganization*Infantry, Post-Reorganization*Armored, and Post-Reorganization*Airborne | | | | | | | | | | | | | | | |
| Variable | Full Sample | | | Fixed Effects Sample | | Only Armored and Infantry | | Only Infantry and Airborne | | Only Armored and Airborne | | Only Pre-Reorganization | | Only Post-Reorganization | |
| Km of Progress | 2.093 | -0.288 | 5.670 | -2.993 | 2.997 | 8.408 | 6.507 | -15.06 | -9.403 | 8.207 | 1.127 | 0.423 | -0.233 | -27.69 | 0.247 |
| | (12.20) | (9.057) | (3.083)* | (3.517) | (3.761) | (9.157) | (5.644) | (21.01) | (6.226) | (10.50) | (1.516) | (4.939) | (0.746) | (128.7) | (6.046) |
| U.S. Fatalities | -1.436 | -1.926 | -0.476 | -0.408 | -0.332 | -1.428 | -0.524 | 0.048 | -0.126 | -1.475 | -0.888 | -1.637 | -0.440 | -4.371 | -0.854 |
| | (0.583)** | (0.625)** | (0.177)** | (0.193)** | (0.387) | (0.768)* | (0.354) | (2.464) | (0.183) | (0.615)** | (0.261)** | (0.576)** | (0.217)** | (12.31) | (0.658) |
| Km 1st Stage F | 0.962 | 0.845 | 1.395 | 0.739 | 6.071 | 1.273 | 1.605 | 0.264 | 1.029 | 0.991 | 3.262 | 1.833 | 0.001 | 0.779 | 2.853 |
| Fatal. 1st Stage F | 23.61 | 8.501 | 17.66 | 4.503 | 4.246 | 7.227 | 12.74 | 0.352 | 10.84 | 5.700 | 4.974 | 4.607 | 0.441 | 5.163 | 10.30 |
| Over Ident. Chi$^2$ | 8.682 | 2.434 | 40.24 | 15.48 | 0.000 | 3.436 | 21.65 | 0.133 | 0.002 | 0.024 | 0.130 | a | a | 0.000 | 0.000 |
| N (Division Days) | 4,430 | | | 1,137 | | 4,107 | | 3,689 | | 1,064 | | 598 | | 3,832 | |
| Clusters (Division Months) | 470 | | | 115 | | 441 | | 371 | | 128 | | 66 | | 407 | |
| Panel B: Division Days in Which U.S. KIA ≥ 5 | | | | | | | | | | | | | | | |
| Km of Progress | 6.955 | -18.58 | -17.82 | -0.996 | 0.273 | -80.49 | -13.85 | 7.891 | -5.597 | 33.66 | 1.554 | -0.846 | -7.537 | -22.39 | -15.57 |
| | (7.509) | (27.46) | (14.28) | (5.292) | (0.327) | (338.1) | (12.37) | (8.692) | (3.833) | (94.89) | (4.155) | (11.65) | (3.529)** | (95.47) | (23.00) |
| U.S. Fatalities | -0.711 | -4.673 | -2.521 | -3.197 | -0.118 | -14.48 | -2.292 | -0.014 | -0.295 | 2.068 | -1.502 | -4.956 | -0.066 | -4.849 | -1.180 |
| | (1.202) | (4.587) | (1.295)* | (3.276) | (0.845) | (53.23) | (1.025)** | (1.141) | (0.229) | (10.44) | (0.893)* | (5.268) | (0.135) | (15.15) | (1.102) |
| Km 1st Stage F | 1.558 | 1.725 | 0.962 | 1.263 | 2.177 | 2.376 | 0.719 | 0.252 | 2.317 | 0.733 | 1.490 | 0.725 | 2.833 | 1.800 | 0.684 |
| Fatal. 1st Stage F | 15.07 | 12.05 | 7.493 | 0.474 | 0.216 | 16.38 | 10.08 | 1.103 | 6.299 | 3.886 | 2.270 | 1.992 | 0.242 | 20.47 | 6.821 |
| Over Ident. Chi$^2$ | 10.95 | 1.033 | 0.424 | a | a | 0.013 | 0.017 | 0.610 | 0.874 | 0.074 | 2.830 | a | a | 0.000 | a |
| Continent & Trnd | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Additional Controls | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Axis Division FEs | | | Yes | Yes | Yes | | Yes | | Yes | | Yes | | Yes | | Yes |
| Cell FEs | | | Yes | Yes | Yes | | Yes | | Yes | | Yes | | Yes | | Yes |
| U.S. Division FEs | | | | | Yes | | | | | | | | | | |
| N (Division Days) | 4,579 | | | 1,221 | | 4,395 | | 3,841 | | 922 | | 621 | | 3,958 | |
| Clusters (Division Months) | 516 | | | 137 | | 488 | | 407 | | 137 | | 82 | | 436 | |

Notes to Table 1: Variables and data are the same as in Appendix Table A3. All specifications control for continent dummies and a daily time trend. Continent dummies include North Africa, Sicily, Italy, and Northwest Europe. Additional controls include numbers of German, Italian, German Panzer, Axis SS, German Parachute, U.S., non-U.S. Allied, and Allied armored divisions in the same cell and numbers in neighboring cells, degrees slope, monthly wet days, precipitation, and mean temperature, dummies for slope > 5 degrees, wet or rainy, wooded or mixed vegetation, and cultivated land, prior days in theater, prior days with U.S. KIA ≥5, and days in the past 30 days with U.S. KIA ≥5. Wet or rainy indicates whether wet days exceeded 20 or precipitation exceeded 125 mm for that cell in that month. Standard errors reported for all coefficients are clustered by division x year x month interaction. The letter "a" as reported for the Over Identification Chi denotes that the equation was exactly identified due to collinearity of the instruments. ** indicates the coefficient exceeds twice the value of its clustered standard error; * indicates the coefficient is more than 1.68 times larger but less than twice its clustered standard error.

Table 2: 2SLS Estimates of the Cost Function for Military Operations, Engagement Data

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dependent Variable is Estimated Cost per Day in Millions of 2009 Dollars | | | | | | | | | | | | | | |
| | Panel A: Mission Effectiveness Measured as Km Progress | | | | | | | | | | | | | | |
| | Excluded Instruments are Indicators for Armored, Post-Reorganization*Infantry, and Post-Reorganization*Armored | | | | | Excluded Instruments are U.S. Troops, U.S. Tanks, and U.S. Troops * U.S. Tanks | | | | | | | | | |
| Variable | Excluding Airborne | | | | | Full Sample | | Low Tank Intensity | | High Tank Intensity | | Fixed Effects Sample | | | |
| Km of | -1,411 | 558.1 | -721.6 | 21.73 | 74.22 | 48.58 | -338.8 | 279.6 | 47.06 | 1,051 | -365.0 | -961.2 | 89.28 | 274.6 | 227.6 |
| Progress | (3,449) | (594.2) | (1,425) | (58.19) | (68.44) | (1,220) | (361.6) | (127.9)** | (27.39)* | (2,009) | (260.9) | (2,265) | (91.69) | (219.3) | (306.0) |
| U.S. | 3.838 | -1.244 | -0.889 | -0.120 | -0.386 | 7.049 | -3.344 | 0.427 | 0.195 | 10.36 | -2.252 | 7.057 | -1.080 | -0.880 | 1.380 |
| Fatalities | (13.61) | (1.414) | (1.833) | (0.178) | (0.170)** | (7.808) | (2.904) | (1.006) | (0.099)* | (17.58) | (1.794) | (12.46) | (0.662) | (0.670) | (1.775) |
| Km 1st Stage F | 0.433 | 0.322 | 0.197 | 2.223 | 1.656 | 0.360 | 1.048 | 3.280 | 2.770 | 1.247 | 2.775 | 0.873 | 1.293 | 1.269 | 0.568 |
| Fatal. 1st Stage F | 0.399 | 0.701 | 1.299 | 5.148 | 11.75 | 0.390 | 0.898 | 0.463 | 20.49 | 0.421 | 2.698 | 0.893 | 1.161 | 2.850 | 0.868 |
| Over Ident. $Chi^2$ | 0.037 | 0.175 | 0.746 | 18.04 | 26.25 | 0.001 | 1.154 | 0.567 | 11.39 | 0.043 | 0.275 | 0.017 | 8.232 | 1.244 | 1.992 |
| | Panel B: Mission Effectiveness Measured with Zero to One Index | | | | | | | | | | | | | | |
| Index of | 2,995 | -760.4 | 2,296 | 4,053 | 2,578 | 578.0 | 3,064 | 5,487 | 727.0 | 7,194 | 4,612 | 13,757 | 4,295 | 41,343 | 5,847 |
| Success | (872.7)** | (2,570) | (925.9)** | (1,562)** | (753.8)** | (13,561) | (1,571)* | (10,558) | (343.5)** | (4,246)* | (2,353)* | (9,711) | (2,565)* | (188,232) | (17,217) |
| U.S. | 0.630 | -1.896 | -0.461 | -0.212 | -0.626 | 6.727 | -1.227 | -2.191 | 0.100 | -0.052 | -0.394 | -2.247 | -1.584 | 6.793 | -2.517 |
| Fatalities | (1.251) | (1.696) | (0.592) | (0.379) | (0.202)** | (12.12) | (0.783) | (4.114) | (0.112) | (1.823) | (0.407) | (3.879) | (1.199) | (35.59) | (8.368) |
| Index 1st Stage F | 10.54 | 5.180 | 6.647 | 2.420 | 4.551 | 3.747 | 5.380 | 0.558 | 3.626 | 1.217 | 1.771 | 1.548 | 1.973 | 1.177 | 1.969 |
| Fatal. 1st Stage F | 0.399 | 0.701 | 1.299 | 5.148 | 11.75 | 0.390 | 0.898 | 0.463 | 20.49 | 0.421 | 2.698 | 0.893 | 1.161 | 2.850 | 0.868 |
| Over Ident. $Chi^2$ | 5.773 | 1.806 | 7.318 | 3.132 | 0.195 | 0.001 | 3.527 | 0.322 | 14.30 | 5.151 | 9.130 | 0.020 | 0.127 | 0.069 | 0.312 |
| Date & Continent | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Sorties & Enemy Inputs | | Yes | | | Yes | | Yes | | Yes | | Yes | | Yes | | Yes |
| Terrain & Weather | | | Yes | | Yes | | Yes | | Yes | | Yes | | Yes | | Yes |
| Human Factors | | | | Yes | Yes | | Yes | | Yes | | Yes | | Yes | | Yes |
| Axis Division FEs | | | | | | | | | | | | | | Yes | Yes |
| U.S. Division FEs | | | | | | | | | | | | | | Yes | Yes |
| N (Division Days) | | | 279 | | | 289 | | 150 | | 139 | | | 225 | | |
| Clusters (Engagements) | | | 152 | | | 162 | | 75 | | 87 | | | 132 | | |

Notes to Table 2: Sortie and enemy input controls include U.S. and German aerial sorties, German troops, German tanks, number of German Panzer divisions, and number of Axis SS or German Parachute divisions in the same cell. Terrain, weather, and vegetation controls include dummies for mountain or river, rugged terrain, wet or rainy, temperate, wooded or mixed vegetation, and urban or con-urban. Human factor controls include an indicator for whether the U.S. was the attacking force and indices for leadership, training and force quality, intelligence and planning, logistics and reserves, morale, surprise, and defensive fortifications. Low and high tank intensity are defined relative to the median. All standard errors reported adjust for clustering by engagement. ** indicates the coefficient exceeds twice the value of its clustered standard error; and * indicates the coefficient is more than 1.68 times larger but than twice its clustered standard error.