

**Web Appendix to “Reducing Risks in Wartime Through Capital-Labor Substitution:
Evidence from World War II”**

Journal of Risk and Uncertainty 52 (2), April 2016

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This web appendix is a supplement to “Reducing Risks in Wartime Through Capital-Labor Substitution: Evidence from World War II.” This document provides more detail than the text and data appendix of the paper on the effects of alternative specifications and the sources and calculations used to construct the datasets used in the study. An exhaustive compilation of the Excel spreadsheets, Stata programs, and Xeroxed archived records used in these calculations will be provided on request.

The remainder of this appendix proceeds as follows. Section I presents auxiliary results to those shown in Figure 3 and Tables 1 and 2 of the main paper. Section II describes the sources and calculations used to construct the division by day panel dataset. Section III describes the engagement data in greater detail. Section IV documents the sources and calculations for the construction of the cost estimates.

I. Auxiliary Results

This next section presents additional results on the effects of organizational structure that help to illustrate the mechanisms and calculations and explore the robustness of the findings. First, we present the numbers corresponding to the isoquant graphs in Figure 3 and use these to compute the cost per life saved using an alternative approach that does not involve 2SLS. Second, we show results from the first-stage regressions in tabular form. Third, we present alternative specifications to probe the sensitivity of the main results.

A. Alternative Cost per Life Saved Calculations

Table A3 presents in tabular form the totals by division type that are shown in Figure 3 of the main paper. Each column shows the totals for kilometers advanced (averaged across combat days in the sample being used), the subjective index of mission success (only for the engagement data), total U.S. deaths, and cost in billions of 2009 dollars for that division type. Rows 1 through 12 show estimates for the pre-reorganization division types, and rows 13 through 24 show estimates for the post-reorganization division types. The eight columns show estimates for the eight specifications shown in Figure 3. The relationships among these different numbers are discussed when Figure 3 is presented in the text; this table is included in the appendix so that the reader is able to see the exact values for each of the numbers in the graph.

In column (1) of Table A3, armored divisions advanced 1.929 km per combat day as compared to 1.058 km per combat day for infantry divisions. Hence, the results from column (1) of Table A3 suggest that replacing infantry with armored would increase the rate of advance by $(1.929 - 1.058) = 0.871$ km per combat day. In the sample column, we see that the post-reorganization armored division advanced 1.706 km per combat day, making it 0.223 km per combat day less than the pre-reorganization armored division. As a first approximation, a policy that would reduce fatalities and hold the rate of advance constant would be to replace pre-reorganization infantry with pre-reorganization armor, thus increasing the rate of advance by 0.871 km per combat day, and then to implement the reorganization of the armored division $0.871/0.223 = 3.906$ times, bringing km advanced per combat day back down to the level of the pre-reorganization infantry division. To calculate the reduction in fatalities from this

combination of policies, we first compute $2,120 - 1,059 = 1,061$ the difference in fatalities between pre-reorganization infantry and pre-reorganization armor, and we add to it 3.906 times the difference in fatalities between pre- and post-reorganization armor ($1,059 - 1,116$), giving us $3.906 * (-57) = -223$. Hence, the total reduction in fatalities from this combination of policies would be $1,061 - 223 = 838$. The increase in dollar costs would be \$4.20 billion - \$1.92 billion plus 3.906 times (\$2.90 billion - 4.20 billion), giving an overall reduction in costs of -\$2.80 billion. The cost per life saved from this combination of policies is -\$2.80 billion divided by 838, or roughly negative \$3.3 million. As mentioned in the main text, when only three division types are included in the sample (in this case, pre-reorganization infantry, pre-reorganization armor, and post-reorganization armor), then this calculation is mathematically identical to the 2SLS procedure used in the paper. A similar type of calculation and equivalent 2SLS procedure are shown in Rohlfs (2006), where the two excluded instruments are U.S. troops and U.S. tanks and the policies involve increasing U.S. tanks and reducing U.S. troops. A variety of different policy combinations can be explored, each giving a different estimate of the cost per life saved.

Table A4 calculates the cost per life saved for six different effectiveness-neutral policy combinations for each of the specifications shown in Table A3. The estimate in the upper left is the same negative \$3.3 million calculated in the paragraph above. The degree to which the second policy is implemented varies across specifications depending on how much is necessary to keep mission accomplishment constant. Each combination shown here includes one reorganization and one replacement of a division type with another. The standard error is computed by running the two first stage regressions (with km of progress and U.S. fatalities as the dependent variables) as a system and applying the delta method (suest and nlcom in Stata). The figures below the costs per life saved show the reduction in fatalities generated by each policy combination. As the results from Table A4 show, the estimated cost per life saved varies considerably depending on the specification and the combination of policies being examined. Across all of the estimates shown, the average cost per life saved is -\$1.2 million and the median cost per life saved is \$0.2 million. It is straightforward to check that, if one considers replacing armored with airborne and then partially replacing airborne with infantry (a combination not shown here), the estimated cost per life saved is the same as the pre- or post-reorganization cost per life saved shown in Table 1 of the main paper.

B. First-Stage Regressions

Tables A5 through A7 present first-stage estimates of the effects of organizational structure on km of progress and U.S. fatalities. Table A5 presents estimates of the combat effects of the pre- and post-reorganization division type indicators using the division by day panel. The dependent variable is kilometers of progress in panel A and U.S. fatalities (the scaled version of U.S. KIA) in panel B. Within each panel, each column shows results from a separate OLS regression. The regressors of interest are an indicator for post-reorganization interacted with each of armored, infantry, and airborne and un-interacted indicators for armored and airborne; pre-reorganization infantry is the excluded division type. In columns (1) to (5), the sample is restricted to division days in which the U.S. division was in the same geographical cell as one or more Axis division. In columns (6) to (10), the sample is restricted to division days in which U.S. KIA was five or greater. The full samples are used in columns (1) to (3) and (6) to (8), and the fixed effects samples are used in columns (4) to (5) and (9) to (10). Columns (1) and (6)

include a time trend and fixed continent effects, as in the first column of Table 1 of the main paper. Columns (2) and (7) add controls for the numbers of nearby Allied and Axis units of different types, terrain, vegetation, weather, and combat experience, as in the second column of Table 1 in the main paper. Columns (3) and (8) add fixed effects for month by year interactions, Axis divisions, and 0.25 x 0.25 coordinate geographical cells, as in the third column of Table 1. The same set of controls is used in columns (4) and (9) as in column (3) and (8); however, the fixed effects samples are used. Columns (5) and (10) add U.S. division fixed effects. Standard errors clustered by division x month are shown in parentheses.

While they vary across specifications, the results from Table A5 are generally consistent with the patterns observed in Figure 3. Shifting from pre-reorganization infantry to pre-reorganization armor appears to increase combat effectiveness. The coefficient on armored in panel B shows a consistently negative effect of pre-reorganization armored relative to pre-reorganization infantry on U.S. KIA. The coefficient on armored in panel A varies across specifications and averages to about zero. Hence, usage intensity appears to have been lower for pre-reorganization armor relative to pre-reorganization infantry, so that the higher combat effectiveness led to similar geographical progress and lower fatalities. The results also suggest that shifting from pre-reorganization infantry to pre-reorganization airborne may have reduced combat effectiveness. In column (9), we observe large negative effects of airborne on progress and fatalities consistent with very low usage intensity. For the other specifications, the effect of airborne on progress switches signs across specifications and is on average slightly positive, and we observe a somewhat consistent and relatively large positive effect of airborne on U.S. KIA, a result consistent with a relatively ineffective force with high usage intensity.

As with Figure 3, the OLS results in Table A5 do not show a clear reduction in combat effectiveness of the armored division following the dramatic reduction in troops and tanks under the reorganization. While they vary somewhat across specifications, we find generally positive effects of the armored reorganization on progress and U.S. KIA, a result that is consistent with an increase in usage intensity. In the fixed effects specifications, however, we do observe a result consistent with a decline in the armored division's effectiveness: the armored reorganization appears to have considerably increased U.S. KIA and decreased or only slightly increased geographical progress. The OLS results for the infantry reorganization tend to show a slight positive effect on progress and a generally negative effect on U.S. KIA, a result consistent with an increase in combat effectiveness, despite the slight reduction in troops. The fixed effects estimates of the effects of the infantry reorganization are similar to the OLS in the division days with five or more U.S. KIA sample. In the division days with one or more Axis unit in the cell, however, the fixed effects estimates show significant declines in progress and U.S. KIA – a result consistent with a decline in usage intensity – and they do not suggest a large increase in combat effectiveness. The estimated effects of the airborne reorganization in column (9) indicates a large negative effect of the reorganization on combat effectiveness, with large declines in progress and large increases in fatalities. For the remaining nine specifications, however, the results are consistent with a positive effect of the reorganization on combat effectiveness. In the progress regressions, the coefficient changes signs across specifications and are on average slightly positive, and we observe a generally negative effect of the airborne reorganization on U.S. KIA.

Table A6 estimates the combat effects of the pre- and post-reorganization division types in the engagement data. Each column shows results from a different regression. The dependent variable is kilometers of progress in columns (1) and (2), the zero to one index of mission success in columns (3) and (4), the trichotomous win-lose-draw success measure in columns (5) and (6), U.S. KIA in columns (7) and (8), U.S. tank losses in columns (9) and (10), and German KIA in columns (11) and (12). All twelve regressions exclude the ten airborne observations. Consequently, the only coefficients of interest are an indicator for armored and the interactions of post-reorganization times indicators for armored and infantry. Additionally, data on tank losses are only available for 215 of the 279 combat days. The specifications in columns (1), (3), (5), (7), (9), and (11) control for a time trend and continent fixed effects; columns (2), (4), (6), (8), (10), and (12) add controls for U.S. aerial sorties, enemy inputs, terrain, weather, vegetation, and human factors. Sufficient data do not exist to estimate these regressions with U.S. or Axis division fixed effects. Standard errors clustered by engagement are shown in parentheses.

As with the division by day results, the estimates in Table A6 are generally consistent with the patterns shown in the graphical results. The estimated effects for armored divisions tend to indicate a positive effect of being a pre-reorganization armored division on combat effectiveness. With the exception of a negative effect on progress in the specification with no controls, we do observe a positive effect of armor on the various measures of mission success, and we observe a negative effect on U.S. KIA; the negative effect on U.S. KIA is large and significant in the specification with controls. We also observe a large and significant positive effect of armored on U.S. tank losses.

The results on the effect of the armored reorganization on the different mission success measures are mixed but generally negative. The estimated effects on U.S. KIA are also mixed, but in the specifications with controls, the effects of the reorganization on U.S. KIA and U.S. tank losses are both negative, and the effects on total U.S. tank losses are large and significant. Hence, usage intensity appears to have declined in response to the armored reorganization; however, the effects on combat effectiveness are unclear. The estimated effects of the infantry reorganization similarly suggest a decline in usage intensity. The coefficients for this reorganization are also mixed for the different outcome measures; however, for the specifications with controls, the effects on success and U.S. KIA both tend to be negative.

Next, Table A7 presents first-stage results from the troop and tank regressions in the engagement data. Rather than measure the effects of division type and the reorganizations, the regressors of interest in Table A7 are U.S. Troops/10,000, U.S. Tanks/100, and the interaction of these two. Hence, these specifications suppose that the effects of division type reflect a more general input-output relationship. The dependent variable is kilometers of progress in panel A, the index of mission accomplishment in panel B, and U.S. KIA in panel C. Within each panel, each column shows results from a different OLS regression. Columns (1) and (2) use the full sample of 289 division days, and columns (3) to (6) use the fixed effects sample. The regressions in columns (1) and (3) control for a time trend and continent fixed effects. Columns (2) and (5) add controls for enemy inputs, terrain, weather, vegetation, and human factors. Column (4) includes a time trend, continent fixed effects, and U.S. and Axis division fixed effects, and Column (6) includes the full set of controls plus U.S. and Axis division fixed effects.

The effects of troops and tanks vary considerably by outcome variable. In panel A, we observe mixed to negative effects of U.S. troops, positive effects of U.S. tanks, and a generally negative troop-tank interaction effect on geographical progress. In panel B, we observe a positive and sometimes large and significant effect of troops, a mixed but generally positive and sometimes significant effect of tanks, and a mixed but generally negative and sometimes significant troop-tank interaction effect on the index of mission success. In panel C, we observe a generally positive and sometimes large effect of troops on U.S. KIA, mixed results for tanks, and a generally negative troop-tank interaction term. Hence, U.S. troops appear to contribute substantially to mission accomplishment in a subjective sense; however, their contribution is not through geographical progress, and it is associated with higher casualties. Tanks appear to increase geographical progress and success but not casualties. Averaging across the specifications, the results suggest that one tank contributes about as much to mission accomplishment as do 34 troops.

C. Sensitivity Analysis

The remainder of this section presents alternative specifications to probe the robustness of the results. Figure A1 and Table A8 show results in which the division by day panel are collapsed to the corps by day level. U.S. divisions' corps affiliations were obtained from Stanton (1984) and supplemented with information from Haskew (2009) on the corps affiliations of non-U.S. allied forces. Locations are then averaged across all divisions in the corps that day, and corps-level progress is estimated based on the location of the average U.S. division in the corps. U.S. fatalities are added up across all U.S. divisions in the corps, and the nearby enemy, terrain, vegetation, weather, and experience variables are averaged across the U.S. divisions in the corps. The division type indicators are also summed across divisions in the corps, so that each instrument measures the number of U.S. divisions of that type in the corps that day. The nearby unit controls are replaced with measures of the numbers of nondivisional units and non-U.S. Allied divisions in the corps. The total number of divisions in the corps is added as a control variable, so that the instruments influence substitution from one division to another and not the adding and subtracting of divisions.

Figure A1 shows the same isoquant graphs as are presented in Figure 3, but for the corps by day specifications. Only the Axis divisions in cell definition of combat days is used, because having five or more U.S. KIA is difficult to interpret in the corps setting when engagement with the enemy might vary across divisions in the corps. In each panel, costs on the vertical axis are the same as in Figure 3. Each division's contribution to U.S. fatalities is measured by regressing U.S. fatalities on pre-reorganization times armored, pre-reorganization times infantry, *etc.* The coefficients on the division type variables are plotted along the horizontal axis. Similar regressions are run with km progress on the left-hand side to determine the values for the mission effectiveness isoquants. Panel A shows results in which no controls are included in the regressions, and panel B shows results in which the full set of controls is included.

The armored and infantry divisions and the post-reorganization airborne division are generally appear in the same places on the graphs in Figure A1 as in Figure 3. The one noticeable difference between the two figures is that the pre-reorganization airborne division has considerably lower fatalities. One primary explanation for the difference in pre-reorganization

airborne is that, due to their small numbers of troops and consequent low combat effectiveness, the 13th and 17th Airborne Divisions were used at low intensity relative to other units in their corps. The general shape from Figure 3 is repeated in panel A of Figure A1, with a steep portion at the higher cost levels and a flatter portion at higher fatality levels, but with kinks in the middle ranges. The differences are somewhat less pronounced, however. Moving from the cost level of the pre-reorganized to that of the post-reorganized armored division on the middle isoquant, the slope is $-\$1.4$ million per life saved. At the lower cost levels, moving from the cost level of the post-reorganized infantry to that of the post-reorganized airborne the slope of the isoquant is $-\$0.6$ million per life saved. When controls are added to the regressions in panel B, we observe a backward-bending portion to the curves, and the slopes of the isoquants are less clear than in panel A.

Table A8 shows the corps-by-day counterparts to the 2SLS regressions in Table 1. Due to the nature of corps organization, it is not straightforward using these data to restrict the sample to specific division types. As in Figure A1, only the nearby Axis forces definition of combat days is used. Columns (1) to (3) are the same as in columns (1) to (3) of panel A in Table 1. Column (4) adds corps fixed effects. Column (5) uses the fixed effects sample in which the sample is restricted to corps that at one time contained a division that was reorganized in the theater. Column (6) adds division fixed effects. Columns (7) to (11) show the same specifications in the just identified case in which the reorganizations are ignored and armored and airborne are the only excluded instruments. The division fixed effects specification is not estimable in this case because armored and airborne are perfectly collinear with the division fixed effects.

The coefficient on km progress in Table A8 tends to be larger than in Table 1 because the cost and value of moving multiple divisions are larger than for moving a single division. The estimated cost per life saved is smaller than in Table 1. When all division types are included in the sample with nearby Axis divisions in Table 1, the average and median cost per life saved estimates are $\$0.9$ million and $\$0.5$ million. In Table A8, the average and median cost per life saved estimates are considerably smaller, and $\$0.2$ million and $\$0.1$ million.

Tables A9 and A10 explore the importance of autocorrelation in biasing the standard errors in Tables 1 and 2. In general, changing the form of clustering has little effect on the overall precision of the estimates. Table A9 shows estimates for the seven columns from Table 1 that do not include any of the fixed effects. Underneath each coefficient, the first number in parentheses is the benchmark standard error, which is constructed by clustering by division \times year \times month. The second number in parentheses is a standard error that corrects for clustering by corps \times year \times month, and the third number in parentheses shows a standard error that corrects for clustering by division. On average, the standard errors are roughly 15% larger when clustering by corps \times year \times month and roughly 15% smaller when clustering by division. Moving from division \times year \times month to corps \times year \times month clustering, only one of the 28 coefficients changes significance, moving from significant to marginally significant. Moving from division \times year \times month to division clustering, one coefficient goes from marginally significant to significant, and another goes from insignificant to significant.

Table A10 shows estimates from the eight columns from Table 2 that do not include fixed effects or the full set of controls. The first row in parentheses underneath each coefficient is

the benchmark standard error that corrects for clustering by engagement, and the second row in parentheses is a standard error that adjusts for clustering by division. The standard errors that cluster by division tend to be roughly 10% larger, and when moving from clustering by engagement to clustering by division, one significant coefficient becomes marginally significant, and one marginally significant coefficient becomes insignificant.

Table A11 shows a handful of alternative specifications for the 2SLS regressions using the engagement data. The benchmark cases with the full sets of controls are shown in column (1) for the specification using division type as the excluded instruments and in column (8) for the specification using troops, tanks, and their interaction as the excluded instruments. Columns (1) and (2) include the full sample excluding the 101st Airborne. Columns (8) and (9) include the full sample. Columns (3), (4), (10), and (11) remove observations in which the U.S. was the defending force. Columns (5), (6), (12), and (13) remove observations in which German aerial sorties were not zero. Columns (1), (3), (5), (7), (8), (10), (12), and (14) include the full set of controls. Columns (2), (4), (6), (9), (11), and (13) remove U.S. sorties and enemy inputs as controls.

The results from columns (1) to (6) and (8) to (13) of Table A11 indicate that the coefficients of interest are somewhat sensitive to how strategic actions are modeled. In ten of the twelve specifications estimated with and without controls for U.S. sorties and enemy inputs, removing those variables from the set of controls reduces the estimated cost per life saved. The magnitude of this effect is nontrivial; however, the general pattern in the data is the same whether or not the U.S. sorties and enemy input controls are included. Across all of these specifications, when all of the controls are included, we obtain average and median costs per life saved of \$1.4 million and \$0.8 million. When the U.S. sorties and enemy inputs are removed from the set of controls, we obtain average and median cost per life saved estimates of \$1.6 million and \$0.4 million. Restricting the sample to cases in which the U.S. was the attacking force or cases with no Axis air support generally increases the estimated cost per life saved; however, it decreases the estimated cost per life saved in the troop and tank regressions using the mission success index. These changes to the specification also have nontrivial effects on the estimates but do not qualitatively affect the pattern of results.

In columns (7) and (14), of Table A11 the cost of the division is assumed to be larger if it has medium tanks than if it has light tanks. The costs are assumed to be proportional to the purchase prices of the items. A light tank is assumed to be 84.9% and a medium tank is assumed to be 110.3% of the cost of a tank used in the benchmark calculations, so that the cost of a 1942 organic armored division is unchanged. Additionally, in column (14), light and heavy tanks are included as separate instruments and are separately interacted with troops. Both columns (7) and (14) drop the one observation in which the fraction medium versus light tanks is not known.

In the regressions in column (7) in which only the cost variable is changed, we see hardly any effect of treating medium and light tanks separately. In the troop and tank regressions in column (14) in which the set of instruments changes as well, treating medium and light tanks separately generates lower but more precise estimates of the cost per life saved in the regressions using km advanced as the mission effectiveness variable, and it produces similar and slightly more precise estimates of the cost per life saved in the regressions using the index of success.

II. Division by Day Panel

This next section describes in greater detail than in the main text of the paper the data used to construct the division by day panel. The three types of data sources described here are the U.S. fatalities data, those measuring Allied and Axis unit locations, and the geographic characteristics.

A. U.S. Fatalities Data

U.S. military fatalities are measured from seven different data sources. These data sources are summarized briefly in Table A12 and are described in greater detail in the paragraphs below. The WWII casualties dataset that is used in the analysis was obtained by combining these sources to obtain non-missing values for a large number of observations and to compare values across the different sources to improve the accuracy of the data.

Reading Room Data (U.S. War Department, 1947). The primary source of fatalities information used in this study is a roster listing all 146,431 combat deaths to U.S. Army ground divisions in World War II, Army Chemical Warfare Service, and suicides and executions of U.S. Army troops. The rosters are meant to be complete, though some missing observations have been found from other sources. For each death, the data include name, serial number, divisional and battalion/regiment affiliation, rank, broad category of military occupation, and type of death (killed in action, died of wounds, or finding of death). For 45.1% of cases, depending on the division, battalion/regiment, and the first letter of the soldier's last name, the exact date of death was hand-entered onto the records near the time that they were printed. Some of the numbers were unreadable or cut off, but accurate dates were recoverable from these data for 40.9% of cases. Additionally, a few pages were missing from the original files. The dataset was Xeroxed from paper records at National Archives II in College Park, Maryland. With the help of financial assistance from the National Bureau of Economic Research and Syracuse University, these paper copies were scanned and sent as pdf files to Comat Technologies, Inc., in Bangalore, India, to have the data hand-entered. Every variable except name was entered. We then performed a first merge with the WWII serials file to identify individuals' names and sent the data back to India to have these names checked and have the correct ones filled in. For all variables except name, a second entry was typed in by me, and every inconsistency was double-checked and updated with the correct value. The data were also compared against the other fatality data sources used in this study and were checked by us and a research assistant at Syracuse University for many types of internal inconsistencies including names appearing out alphabetical order, unusual clusters of letters in names, and duplicate serial numbers.

Airborne Division Deaths (U.S. Airborne in WWII, 2010). One secondary source of U.S. deaths that is used in this study include name, rank, division, battalion or regiment, company (in many cases), general location, date of death (in nearly all cases), type of death (in some cases), and cemetery for all 9,209 combat and non-combat deaths to airborne divisions, including deaths to attached units. These data do not include serial numbers; however, matches were generally possible with other data sources based on name, unit, rank, and date of death. These data were

downloaded in electronic form from a website entitled “U.S. Airborne in WWII” in January, 2010.

WWII Honor List (U.S. War Department, 1946). These data include the name, rank, type of death, branch of service (Army including Army Air Forces, Navy, Marines, and Coast Guard), hometown, state, and (for Army) serial number for all 307,185 U.S. Army military personnel who died in World War II, including battle and non-battle dead and missing personnel for ground and air forces. The data do not include unit affiliations or date of death, but they constitute one particularly complete listing of the names and serial numbers of WWII casualties. These lists are provided as multiple pdf files on the NARA website. The American Battle Monuments Commission (ABMC) had an outside company hand-enter the data, and they provide the data along with data from the corresponding lists for the Navy, Marines, and Coast Guard personnel, on the National WWII Memorial website. The dataset is labeled on that site as “National Archives Records.” A complete electronic copy of this dataset was obtained from ABMC through a Freedom of Information Act (FOIA) request submitted in January, 2009.

Machine Records Data (U.S. War Department, 1944). Another archival source of U.S. fatalities includes all 101,250 dead, missing, captured, and wounded personnel, battle and non-battle, for all military branches from 1941 through 1943. The data include name, serial number, home county, rank, broad category of military occupation, type of casualty, and date of casualty. Xeroxes of these files were purchased from Archives II, scanned, and sent as pdf files to Comat Technologies, Inc., in Bangalore, India, to have the data hand-entered. To save on time and expenditures, the name was not entered, and no second entry was made for any of the variables. However, the data have been merged with the other sources and checked for internal consistency to ensure the accuracy of the resulting casualties database. The rosters are organized by state and county in the hard copies, and some pages are missing from the originals. The last page in the Montana records include only casualty from Musselshell County, Montana; the remaining casualties from Musselshell County, Montana and casualties from counties that come alphabetically after Musselshell (Park County through Yellowstone National Park) are missing.

ABMC Cemetery Files (U.S. ABMC, 2005). These data include name, serial number, branch of service, divisional and battalion/regiment affiliation, rank, type of death, date of death, date of birth, age, home town, burial plot location, and awards won for 180,735 WWII battle and non-battle deaths from any branch of service buried in American memorials and overseas military cemeteries. These data are not representative and do not include individuals who were not recovered or were buried in non-military cemeteries; however, they include an extensive set of variables for the observations that are included. These data are available as a searchable database on the ABMC website. A complete electronic copy of the data was purchased for \$50 from ABMC in September 2008.

AGRS Remains not Recovered File (U.S. American Graves Registration Service, 1954). These data include name, serial number, rank, branch of service, and date of loss for all 79,021 dead or missing American military personnel whose remains had not been recovered as of 1954. A cleaned version of these data is available on multiple web pages on the website of the Defense Prisoner of War / Missing Personnel Office (DPMO); however, the cleaned version excludes many personnel whose remains were recovered after 1954. Consequently, an electronic copy of

the original, uncleaned version of these data was obtained through a FOIA request sent to the Department of Defense FOIA Office on March 2009 and forwarded to DPMO.

WWII Serials Files (U.S. National Archives and Records Administration, 2002). These data include name, serial number, home state and county, enlistment location, date of enlistment, rank, branch of service, term of enlistment, country of birth, year of birth, race and citizenship, education, civilian occupation, marital status, and component of the army for 8,706,394 military personnel who enlisted between 1938 and 1946. Draftees are included in the sample, but officers are not. These data were purchased in electronic form from the Electronic and Special Media Records Division of the National Archives and Records Administration (NARA), who created the dataset from the Army's original computer punch cards.

Adjutant General Final Report (U.S. Army Adjutant General, 1953). This final report from includes tabulations and breakdowns of the battle casualties (including dead, wounded, captured, missing) and non-battle deaths of U.S. Army personnel from 1941 through 1946. The two-way tabulations include different types of casualties and deaths by division, by theater, and by month of occurrence. This dataset was used in earlier versions of this study to check totals and remains a valuable source to check totals and compare cross tabulations.

The Reading Room Data are treated as the main data source for fatalities. In many cases, the year was cut off from the data of death in the original file; in these cases, a likely year was estimated based on the dates of death of other members of that unit. Dates of death that occurred outside the dates that the division was at sea were recoded to missing. The airborne deaths were dropped and replaced with information from the U.S. Airborne in WWII website. These airborne deaths were merged with the Reading Room Data, the ABMC Cemetery Files, and the WWII Honor Lists to obtain independent confirmation of the observations. Non-combat deaths, deaths that were confirmed to have occurred in another unit, and deaths that could not be confirmed in another source were dropped. Date of death was first taken from the Reading Room Data, then the airborne data, then the imputed Reading Room Data, then the ABMC data, then the Machine Records data, and finally the Remains Not Recovered Data. The priority of the merge was determined based on the rates of agreement between the different sources. The vast majority of date observations were taken from the Reading Room, airborne, imputed reading room, and ABMC data, which all have 95% or more agreement among the non-missing observations.

B. Unit Locations

The information on unit locations that is used in this study comes from a variety of sources, mainly secondary, such as atlases of WWII, orders of battle, and memoirs.

U.S. Unit Locations. For each American ground division, Stanton's (1984) U.S. Order of Battle in WWII contains a historical account of the cities visited on different dates. Additional data on the 10th Mountain Division's locations were obtained from Imbrie and Imbrie (2004). For each WWII ground division that fought in the European or Mediterranean Theaters, these data were hand-entered into a spreadsheet of 1,565 different division-date-location combinations for 67 U.S. divisions. The geographic coordinates of different cities were obtained from Google Earth and from U.S. National Geospatial-Intelligence Agency (2006), with all cases double-checked

using Google Earth. For cases in which multiple cities had the same name, the city was selected that was closest to the cities visited before and after. Location was not known for most dates and divisions – for in-between dates, each division’s was interpolated assuming that longitude and latitude changed linearly at a constant speed from one location to the next. The 1,565 total includes observations that were added to the data to insure that travel along a straight line would keep the observation on land.

Non-U.S. Allied Unit Locations. The Allied countries other than the U.S. whose divisions’ are tracked in these data include Australia (Haskew, 2009; Maughan, 1966; Pimlott, 2006; Wikipedia, 2010a), Brazil (McCann, 1974; Moraeas, 1966) Canada (Copp, 2006; Natkiel, 2006; Pimlott, 2006; Nicholson, 1956; Wikipedia, 2010b), France (including Algeria and Morocco, Natkiel, 2006; Pimlott, 2006; Stone, 1999, Wikipedia, 2010c), India (Joslen, 2009), New Zealand (Kay, 1967; Llewellyn, 1949; McKinney, 1952; Natkiel, 2006; Phillips, 1957; Pimlott, 2006; Wikipedia, 2010d), Poland (Copp 2006; Natkiel, 2006; Nicholson, 1956; Pimlott, 2006), South Africa (Joslen, 2009; Pimlott, 2006), and the United Kingdom (Joslen, 2009). These sources include published orders of battle, official histories, atlases of WWII, and some online sources. Countries such as Greece that only provided non-divisional units or those such as Czechoslovakia or the Philippines that did not serve on the Western front are excluded from the analysis. Italy, which had only a limited military presence in the Allies following its withdrawal from the Axis, is also excluded. The approaches for identifying the coordinates and imputing are the same as for the U.S. divisions.

Axis Unit Locations. German and Italian force locations were obtained from a variety of sources, among them published orders of battle, unit histories, memoirs, and atlases of WWII (Axis History Factbook, 2009; Bishop and McNab, 2003; Dupuy, 1962; Dupuy, Bongard, and Anderson, 1994; Evans, 2002; Howe, 1993; Jordan and Wiest, 2004; Keegan, 2006; Kurowski, 1995; Messenger, 1989; H. Meyer, 2005; K. Meyer, 2005; Mitcham, 2007a, 2007b, 2007c, 2007d, 1985; Natkiel, 2006; Pimlott, 2006; Terry and Cole, 2001a, 2001b; von Luck, 1989, von Mellenthin, 1956; Zetterling, 2000). The German list of divisions was obtained from Mitcham (2007a, 2007b, 2007c, and 2007d), and the Italian list of divisions was obtained from Axis History Factbook (2009). In many cases, divisions’ locations were identified from a higher level of organization such as the Army or corps together with information from Axis History Factbook (2009) on the Axis Army’s organizational structure. A total 5,082 different division-location combinations were obtained from these sources, with coordinates identified and in between locations imputed in the same way as for the Allied divisions. Vichy France was not included in the data collection because its opposition to Allied forces only lasted for a brief time in November 1942.

C. Geographic Variables

The key geographic variables used in the division by day panel are those measuring terrain, weather, and vegetation. Additionally, the cost distance tool in ArcGIS was used to determine land distances from one location to another.

Terrain (U.S. Geological Survey, 2005). Elevation data for Europe and North Africa were obtained from U.S. Geological Survey (USGS, 2005). These data were compiled by NASA and

USGS from space shuttle photographs taken in 2000 and consist of elevation values at points spaced 3 arc seconds (roughly 90 meters) apart from one another along a grid. The slope at a given point is calculated using the slope tool in ArcGIS. This tool measures the change in elevation (in degrees) between each point and its eight neighbors (north, northeast, *etc.*) and returns the steepest (up or down) of these eight different slopes. This slope variable is commonly used by geographers as a measure of the difficulty of traveling over terrain in a given area.

Weather (Mitchell and Jones, 2005). Historical weather data are taken from the Climactic Research Unit's CRU TS 2.1 Global Climate Database. These data measure near-surface mean temperature, precipitation, number of wet days, and other variables by month and year at the 0.5 x 0.5-coordinate level for the entire world going back to 1901. The set of weather stations used to construct the data varies from year to year, and imputation and climate modeling is used to fill in missing observations. In addition to the imputation used to construct the data, an additional 549 observations in the division by day panel required imputing the weather variables as averages of the neighboring cells that month.

Vegetation (Goldewijk, 2001). The vegetation data used in this study are estimates that were compiled by the author of the dataset for every fifty years from historical surveys such as tax records and land surveys. The data place each 0.5 x 0.5-coordinate cell into one of twenty land use categories based on the amount of vegetation. The 1950 data are used for the current study. The "cultivated land" dummy used in the division by day panel is one of the twenty categories, and the "wooded or mixed" dummy indicates whether that 0.5 by 0.5-coordinate cell was in one of the eight land cover categories whose description included the word "wood" or "forest."

III. Engagement Data

The engagement data used in this study are the result of a long-term data compilation effort by The Dupuy Institute and its predecessor organization, the Historical Evaluation and Research Organization (HERO) that began in the 1960s. The Dupuy Institute's Division-Level Engagement Database (DLEDB) is a cleaned and expanded version of an earlier database entitled the Land Warfare Database (LWDB). Both datasets include a large number of battles from antiquity to the present and have been analyzed as a set by a handful of economists and operations researchers including Hartley (2001), Helmbold (1993), and Rotte and Schmidt (2003). The data are described in detail in The Dupuy Institute (2001a, 2005). Additionally, the dataset as a whole and many specific observations are described in greater detail and examined from the perspective of quantitative historians in sources such as Dupuy (1985, 1987, 1995), Lawrence (1996, 1997), and The Dupuy Institute (2000, 2001b, 2004). The LWDB is publicly available as a CD-ROM in the back of Hartley (2001). The DLEDB is proprietary and may be purchased from The Dupuy Institute.

One of the key variables from the engagement data used in this study that appears both in the DLEDB and in the LWDB is the subjective index of mission accomplishment. Figure A2 shows the worksheet used to calculate this zero to one mission accomplishment index. As the figure shows, each unit is scored on five criteria. The first three criteria relate to specific mission objectives. These include conceptual accomplishment (a general evaluation of achievement of mission objectives), geographical accomplishment (*i.e.*, kilometers advanced), and block hostile

mission. Together, these objective-based scores can range from zero to six. In addition to these three objective-based measures, the index incorporates general evaluations of the performance of officers and enlisted men. Together these general evaluations can range from zero to four points. In principle, each side's mission accomplishment can be evaluated separately and ranges from zero to ten. In practice, attacker and defender mission accomplishment are nearly perfectly negatively correlated. Mission accomplishment ratings do not exceed nine for either side for the 162 engagements used from the DLEDB. The measure of mission accomplishment used in this study and in the previous section is $(\text{U.S. total score} - \text{German total score})/16$.

One limitation of this subjective mission accomplishment measure is that it assigns equal weight to each of the five criteria. Ideally, it would be possible to vary the weights for these criteria depending on their relative importance in different missions. Another possible limitation of this subjective mission accomplishment measure is the emphasis on troops. Command and staff performance and troop performance are both rated separately from accomplishment of specific objectives. No such rating exists, however, for the performance of capital. Given the available measures, this subjective index appears to be the best way to quantify mission accomplishment.

IV. Cost Calculations

As discussed in the text of the paper, the per troop and per tank cost estimates are derived from estimates of the cost of raising and operating an organic infantry and armored division according to the 1942 configurations. These costs take into account pay, training, capital expenses, depreciation, food, clothing, gasoline, ammunition, and transportation. The costs calculated here include all costs incurred between the activation of a division and its return from overseas, including the return trip. These estimates omit many overhead expenditures such as planning and research and development. While all the Army divisions benefited from these expenditures, these costs do not have to be paid again when replacing a division.

Table A13 shows estimated total wartime costs for infantry and armored divisions that spent typical amounts of time abroad. All cost estimates are expressed in 2009 dollars and are converted using the Consumer Price Index. The costs shown in Table A13 are calculated using separate estimates of a typical division's fixed costs plus additional costs per months abroad. For most major expenditure categories, these estimated costs are very similar for infantry and armored divisions. The biggest cost differences between the two types of divisions are for equipment and transportation. For an infantry division, equipment costs totaled \$119.80 million initially plus \$4.30 million per month abroad. For an armored division, equipment cost about ten times as much at \$1.114 billion initially plus \$71.00 million per month abroad. For a 10.8-month deployment, we find that a 1942 organic infantry division cost \$1.43 billion and a 1942 organic armored division cost \$4.10 billion.

Dates of Service and Dates Abroad

Activation and de-activation dates and dates abroad for each division are taken from Stanton (1984, pp. 47-182). The number of months in the theater for the average division is

computed from the division by day panel as 10.76. The average number of days in the theater for the average division is computed as 298.8.

Pay and Allowances

To compute pay rates for different soldiers, official pay scales are used from the *Pay Readjustment Act of 1942* (U.S. Congress, 1942). This document provides the pay scales for military personnel based on rank, tenure, and special circumstances (e.g., additional skills or overseas service). Assumptions about skills are described later in this appendix. The rank composition of infantry and armored divisions is obtained from Hays (2002, 2004).

Because pay depends on tenure, a level of tenure is assumed for each troop. These assumptions about tenure have little effect on the final cost figures but are necessary to obtain wage estimates. The vast majority of officers and enlisted men who fought in World War II were inducted from civilian life (Palmer, Wiley, and Keast, 1991, pp. 91-92). However, the higher-ranking officers were typically career military. It is assumed that men in the core officer cadre (described below) had the average tenure levels for their ranks. It is assumed that other officers and enlisted men had zero tenure when they underwent training. After training was complete, it is supposed that all these troops had the average tenure levels for their ranks. It is also assumed that the division had this same post-training tenure composition throughout the life of the unit. Average tenure levels for officers are estimated using average pay data from U.S. War Department Bureau of the Budget (1946). Given average pay and the formula relating pay to tenure (from U.S. Congress, 1946), average tenure levels are imputed for each rank. A similar exercise is performed for enlisted men using average pay data from U.S. Army Office of the Comptroller (1953). Using pay scales from U.S. Defense Finance and Accounting Service (2006), average tenure for enlisted men is estimated by rank for 1953. These 1946 and 1953 average tenure levels are used to proxy for average tenure in 1942, the year of interest.

During World War II, retirement pay was limited to officers who had served for at least 10 years (U.S. Congress, 1942, pg. 368). These men would have probably been employed in the absence of the war. Veterans' benefits were expanded later on, but it is likely that these changes were unanticipated at the time that the troops were procured. Consequently, retirement pay and other veterans' benefits are not counted for the purposes of this exercise.

Training

Initial (pre-departure) training expenditure calculations begin with the January 1942 plan for activation of an infantry division (Palmer, Wiley, and Keast, 1991, pp. 433-441). This plan specifies the lengths of time spent in training for all 15,514 troops in an organic infantry division. It is assumed that the sequence of events in activation and training was the same for armored as for infantry divisions. A division usually began with a cadre of trained, high ranking officers taken from other "parent" divisions. For infantry divisions, this cadre included 172 officers.¹

¹ Later in 1942, the activation schedule was changed slightly, and a greater proportion of officers were hired for the pre-trained cadre (Palmer, Wiley, and Keast, 1991, pp. 436-438). Accounting for such changes would have only a minor effect on our estimated costs.

Given the larger numbers of high ranking officers in an armored division, it is assumed that the armored officer cadre included 183 officers.²

The high ranking officers within a division acted as instructors for most of the division's training. This training included both basic instruction and field exercises performed at camps throughout the U.S. Palmer, Wiley, and Keast suggest that the typical training period for a division was 38 weeks (Palmer, Wiley, and Keast, 1991, pp. 440-441, 481). Data from Stanton indicate that 789 and 803 days passed between activation and departure overseas for armored and infantry divisions, respectively (Stanton, 1984 pp. 47-182). Hence, the divisions spent a considerable amount of time after training simply shuffling around and waiting to depart.³ The personnel costs in Table A13 include wages paid during this idle time. Most of the division's pre-debarkation wages are included as personnel costs in Table A13, even when the personnel worked as instructors.⁴

The total costs of division field exercises are calculated from U.S. Bureau of the Budget (1940-1947).⁵ The cost per set of maneuvers is estimated by dividing this total cost across all divisions in proportion to their participation. Stanton (1984) reports the dates in which each division participated in field exercises. The average armored and non-armored divisions participated in 1.6 and 2.0 sets of combat maneuvers, respectively. It is assumed that the armored:infantry cost ratio for field exercises was 1.25, the same as for replacement training camps. Estimates of replacement training camp costs are described later in the appendix.

All the officers and some of the enlisted men received training prior to the activation of the division.⁶ Every officer received both basic enlisted training and some form of basic officer candidate training. The higher ranking enlisted men received basic enlisted training before joining the division. Roughly 33% of the officers and roughly 6% of the enlisted men also received advanced training in some special skill.⁷ Troops within the division served different

² This estimate is obtained by assuming that the ratio of cadre to other officers was the same as for the infantry division.

³ Brown (1986, pp. 164-167) describes this process in further detail.

⁴ For training before the division was activated (*e.g.*, basic enlisted training, Officer Candidate School), trainee wages are included in the cost of training. It is supposed that basic training for enlisted men and officers occurred prior to activation of the division. Hence, the total costs of basic, officer, and Command and General Staff training include the wages and allowances paid to trainees. Advanced training appears to have frequently taken place after the activation of the division (Palmer, Wiley, and Keast, 1991, pg. 265). Hence, these men would have been employed by the division if they were not receiving the training. The cost of advanced training estimated here excludes trainees' wages and allowances. It is supposed that troops held the rank of Private during basic enlisted training and Private First Class during officer candidate training. It is supposed that they held the rank of Second Lieutenant during Command and General Staff Training. During all other training, it is supposed that the trainees held their ultimate ranks within the division.

⁵ These estimates exclude the costs of additional military personnel who worked at the training camps. From preliminary investigations, it was determined that these additional costs are negligible.

⁶ The original officer cadre included officers who had already received training for other purposes. These officers were often taken from other "parent divisions." The cost of the division does not include the cost of training these officers. However, the division was responsible for training replacements for the officer cadre in their parent divisions. These replacement training costs are included in the cost of the division.

⁷ It is supposed that advanced training went to higher ranking officers and enlisted men and to the ranks with "technical" in the title. Both the 33% and 6% figures are rough approximations based on a variety of figures (Palmer, Wiley, and Keast 1991, pp. 249, 266, 279, 308-319). For an enlisted man who learned a special skill, the

functions (Artillery, Infantry, Quartermaster), and each troop attended schools particular to his branch. Data on the breakdown of infantry and armored divisions by branch are taken from Hays (2002, 2004) and Greenfield, Palmer, and Wiley (1947, pp. 320-321).

Next, the lengths and types of training are estimated for each troop. Troops were generally processed through induction stations and reception centers. Each of these processes lasted a day or two (U.S. Army Chief of Staff, 1945a). From early in mobilization until April 1943, basic enlisted training lasted 13 weeks. Officer candidate school also typically lasted about 13 weeks during this period. By late 1943, both types of schooling had been lengthened to 17 weeks (Palmer, Wiley, and Keast, 1991, pp. 332, 358, 382-385). For the purposes of this analysis, it is assumed that the divisions' initial troops received the shorter, 13-week training. Replacement troops are assumed to have received the longer training. Specialist courses varied in length. For each troop, it is assumed that specialist training lasted the average length for enlisted or officers for that branch. These average lengths are calculated using course lengths and output data from Palmer, Wiley and Keast (1991, pp. 309-319).⁸ Some specialist course lengths are also taken from U.S. Army Ground Forces (1947). It is also supposed that the divisions' highest ranking officers attended Fort Leavenworth's 10-week Command and General Staff course.⁹

Next, the cost per week of training is estimated for different types of training. Estimates of the cost per week of officer training are obtained from U.S. Army Ground Forces (1947). This report consists of an itemized accounting of different types of training given to Chinese officers in 1947. This report includes the estimated costs and lengths for a variety of courses in ground arms, service branches, and Command and General Staff.¹⁰ It is assumed that the advanced specialist courses cost as much for enlisted men as for officers. To estimate the cost per week for basic enlisted training, these costs are combined with data from a few different sources.¹¹ Some

Army paid an additional allowance. It is assumed here that this bonus coincided with taking the enlisted advanced courses.

⁸ For the Officer Candidate School basic training, total training costs include the cost of training students who did not graduate. These costs are added in by scaling the course length by the branch-specific graduation rate. Data on graduation rates are obtained for the branches of the ground arms (*e.g.*, Artillery, Armor, Infantry) from Keast (1946, pp. 27-34). Data on the overall graduation rate of the service branches (*e.g.*, Ordnance, Signal, Quartermaster) are obtained from U.S. Army Service Forces (1954, pg. 224). We assume that the Command and General Staff graduation rate equaled the average graduation rate for basic officer courses in the ground arms. For the basic enlisted training, it is assumed that the induction centers effectively screened enlisted men, and that the graduation rate was 100%. For advanced courses, it is assumed that the knowledge (rather than the degree) was relevant for division effectiveness, and hence pass rates are ignored.

⁹ During World War II, the typical 1- to 2-year course was abbreviated to 10 weeks (Partin, 1983).

¹⁰ We also constructed our own estimates of the average training costs per pupil based on the schools' non-personnel budgets and the total personnel. Our estimates are slightly larger than these cost estimates, but are generally of the same order of magnitude. The Army Ground Forces data are used for the final estimates, because they exhibited less variance and required fewer assumptions.

¹¹ For each branch, it is assumed that the non-labor cost per pupil was the same for officer training as for enlisted training. Non-labor costs for the officer candidate schools are obtained from U.S. Bureau of the Budget (1940-1947). It is then assumed that the personnel cost per pupil was proportional to the number of personnel per pupil in each school. The personnel per pupil for enlisted and officer schools are obtained from U.S. Army Chief of Staff (1945a through 1945d). It is supposed that the labor cost per employee was the same for these schools as for the corresponding branch of officer training. For the service branches, data on non-labor costs were not readily available. It is assumed that the non-labor cost per pupil in the Signal Corps was the same as for Field Artillery. It is also assumed that the non-labor cost per pupil for Ordnance and the Quartermaster Corps were the same as for Infantry. For the Medical Corps, the personnel to student ratio was very similar for basic enlisted and enlisted

minor imputation was required in calculating each of breakdown by branch, course lengths, and cost per week.

In addition to the initial mobilization strength, each division received replacement troops when it lost troops due to casualties or other separations. The cost of regular replacements of troops is estimated by combining the above pay and training estimates with data on separations. Casualty rates, separation rates, and returns to duty (among casualties) are measured separately for officers and enlisted men from a handful of sources. For separations other than casualties, the cost of replacements is included in the monthly cost of operating a division overseas. Data on the rate of separations are obtained from U.S. Army Service Forces (1954, pp. 200, 206-209). Data on the rate of casualties (minus returns-to-duty) are obtained from U.S. Army Adjutant General (1953, pg. 5). Using these data, the monthly rates of non-casualty separations are calculated separately for officers and enlisted men. Within each enlisted/officer and branch combination, it is assumed that replacements took specialist courses at the same rate as the division's original troops. However, replacements generally did not receive divisional training or participate in maneuvers. For casualty replacements, the casualty rate per branch is estimated from a handful of sources.¹² Using these pay and training data, the replacement cost per casualty is estimated to be \$6,400. This cost of replacing casualties is not included in the estimated costs of the divisions. Death benefits and funeral and cemetery expenses were negligible compared to this \$6,400 replacement cost (U.S. Bureau of the Budget, 1940-1947; U.S. Congress, 1919).

Capital Expenditure

Quantities of equipment for organic infantry and armored divisions are taken from Hays (2002, 2004). Purchase prices for each item are taken from U.S. Army price lists (U.S. Army Air Forces, 1945; U.S. Army Service Forces (1942a, 1942b, 1943a, 1943b, 1943c, 1944a; U.S. Army Services of Supply 1942a, 1942b). These prices are adjusted using branch-specific monthly procurement price indices from Crawford and Cook (1953, pg. 82). Depreciation rates for specific capital items are taken from U.S. Army Service Forces (1943d, 1944b, 1944c) estimates. These depreciation rates take into account tank losses both in and out of combat.¹³ In many cases, Army Service Forces estimated separate depreciation rates for different theaters. When separate depreciation rates were available for the Mediterranean and European Theaters of Operations, an average of the two rates was used. When this was not possible, depreciation rates were used for the overall Western Front or for the entire overseas army. Maintenance and loss data from overseas were limited, and these estimated depreciation rates are at best very rough

specialist schools. Consequently, it is assumed that the cost per trainee week was the same for officers and enlisted men. For Military Police and Engineer Corps, personnel to student ratios are not readily available for both officer and enlisted courses. For these two branches, it is assumed that the cost per trainee week was the same for enlisted men as for officers.

¹² U.S. Army Adjutant General (1953), pg. 5. Palmer, Wiley, and Keast (1991), pg. 49. U.S. Army Service Forces (1954), pg. 123. Some branches aggregated. Some minor imputation required. It is supposed that the ratio of enlisted to officer casualties was constant across the different ground arms and service branches.

¹³ Constant monthly depreciation rates are assumed, as U.S. Army Service Forces did when determining replacement requirements. These depreciation rates take into account tank losses from combat. Simply using tank loss rates from the engagement data would fail to account for tank losses out of combat. Moreover, the engagement-level tank loss data do not specify the degree of damage or reparability. These constant monthly depreciation rates appear to be the most accurate way to account for tank losses.

approximations. In a small handful of cases, the price or depreciation rate for a specific item was not available. In these cases, the data for similar items were used. For the 38 weeks of division training, it is supposed that equipment depreciated at the reported rates for the Continental U.S. This depreciation is counted as a cost of training in Table A13. For the remaining idle time before debarkation, it is supposed that equipment did not depreciate.

The effects of division type on tank losses in Table A6 are notable because they are used in the cost calculations. For the average combat day in the engagement data, 3.4 out of 125 U.S. tanks were lost in combat. The percentage lost in a combat day was 1.1% and 2.8% for pre- and post-reorganization infantry and was 3.5% and 4.6% for pre- and post-reorganization armored. To translate these figures into estimated losses per month, we multiply these percent losses by the number of days in the engagement sample that a unit would be expected to experience over a month. We then scale the losses upward to account for tank losses that occurred on days that are not in the engagement sample. Because tank loss data are only available in the engagement sample, we perform a scaling using the fatalities data – measuring the fraction of deaths attributable to engagement days. This same scaling is used to construct the U.S. KIA bar graphs and the isoquant graphs in the main paper. To perform the scaling, we multiply the percentage of tanks lost by 298.803 (the number of days in a typical deployment) times 0.0146544 (the fraction of division days included in the engagement sample) and we divide by the product of 0.0589803 (the fraction of deaths accounted for by the engagement sample) and 10.75758 (the number of months in a typical deployment). For the infantry divisions, this calculation produces monthly loss rates of 7.83% pre-reorganization and 19.3% post-reorganization. For the armored divisions, this calculation produces monthly loss rates of 24.0% pre-reorganization and 31.7% post-reorganization. The differences between pre- and post-reorganization types are largely due to the more intense combat and higher tank losses experienced in the ETO than in the Mediterranean Theater. Considering pre- and post-reorganization together, we estimate monthly tank losses of 11.2% for the infantry division and 29.8% for the armored division. Army Service Forces varied its tank loss estimates over the course of the war based on the higher than anticipated loss rates; these figures are roughly in line with their end-of-war estimated loss rate of 20% (Smith, 1959, pp. 189-91). Given the lower percentage of armored divisions in the theater, the observed tank loss rates fall slightly below this 20% figure; however, the loss rates from the engagement data do not take into account standard wear and tear and tank losses that did not occur during combat (which probably occurred more frequently than non-combat fatalities). To adjust for this deficiency, the monthly depreciation rates from Army Service Forces are revised upwards in the tank loss estimates, and a 15% monthly depreciation rate is assumed for tanks in infantry divisions, and a 35% monthly depreciation rate is assumed for armored divisions.

Food, Clothing, Gasoline, and Ammunition

The food, clothing, gasoline, and ammunition costs estimated here rely on historical U.S. Army cost studies. Estimates of a single troop's food requirements are taken from U.S. War Department Public Relations Division (1946). Clothing and additional equipment estimates are taken from U.S. Army Office of the Quartermaster General (1944).¹⁴ Both per troop estimates

¹⁴ These Quartermaster General estimates include both initial costs and monthly maintenance costs. These totals include “additional equipment” such as canteens, flashlights, etc. These costs are added to the “Equipment” category in Table A13. As suggested by the study, the estimates here add 25% of the initial costs for reserve requirements.

are then multiplied by the number of men in each type of division. Monthly overseas ammunition cost estimates for a 1942 armored and infantry division are obtained from U.S. Army Services of Supply (1943, pg. 30). Monthly overseas gasoline requirements for a 1942 armored and infantry division are obtained from U.S. Army Service Forces (1943a).¹⁵ Gasoline prices for 1942 are taken from U.S. Bureau of Labor Statistics (2004).

Transportation

Transportation costs are estimated separately for troops and for capital items from the travel and transportation portions of the U.S. defense budget (Greenfield, Palmer, and Wiley, 1947, pg. 203; U.S. Bureau of the Budget, 1940 to 1947).¹⁶ These expenses are divided by the total numbers of people and tons shipped overseas to obtain average costs per person and per ton (U.S. Army Service Forces, 1954, pp. 116, 123). Hence, it is assumed that the per person and per ton transport costs were the same for the Pacific and Western Fronts. These costs include the total expenditures incurred by the Transportation Corps for inter- and intra-continental transport for people and items shipped overseas. Given all these assumptions, the total transportation cost per ton shipped overseas is estimated to be \$880 in 2009 dollars. The total transportation cost per troop who traveled overseas is estimated to be \$3,600.

The total weight of infantry and armored divisions' equipment is taken from U.S. Army Service Forces (1943a). Two-way trips are assumed for initial troops and equipment, and one-way trips are assumed for replacements. It is assumed that maintenance shipments had the same weight per dollar of expenditure as the initial shipments did. In addition to regular purchases, Army supply plans included a 4.5-month store of reserves.¹⁷ Hence, 4.5 months of equipment, gasoline, and ammunition are added to the fixed cost of each division type. Costs are also adjusted for 2% shipping losses for all equipment, as suggested in Herbert and Richards (1943, pg. 21).¹⁸

Numbers of Troops and Tanks

The standard numbers of troops and tanks for each division type varied over time and are illustrated in Figure A3. The solid black line in panel A shows the number of troops for an armored division, the dashed line shows the number for an infantry division, and the solid gray line shows the number for an airborne division. The standard numbers of tanks are plotted in panel B; however, only the solid black line for the armored division is visible, because no tanks

¹⁵ These studies do not report monthly ammunition or gasoline requirements for units still in the U.S. To compute U.S. rates, it is supposed that the ratio of gasoline and ammunition usage to capital depreciation was the same as it was overseas.

¹⁶ Personnel costs for the Transportation and Quartermaster Corps are calculated assuming that employees in these branches received the average Army pay rates.

¹⁷ Supplies ran very low near the end of the war. As Anderson (2000) describes, to supply units in the field, some divisions were stripped of their equipment as soon as they arrived overseas. Hence, the true amounts of reserves maintained overseas may have fell considerably lower than this 4.5 months figure. One additional cost of reserves is the cost of storage space. A preliminary examination of storage costs revealed that they were negligible. Sources: Hamilton (1953), pg. 28; U.S. Army Ground Forces (1945); U.S. Army Service Forces (1943e), pp. 27-B to 29-B; U.S. Army Service Forces (1954, pp. 106-110). U.S. War Department Office of the Budget Officer (1943).

¹⁸ In other words, all equipment costs are divided by 0.98 to allow for shipping losses.

were allotted to the standard infantry or airborne divisions. The numbers for Figure A3 come from Hays (2002, 2003a, 2003b, 2004) and many were confirmed in Stanton (1984) and Wilson (1998).

To measure the numbers of troops and tanks once attachments are taken into account, the full attachment histories are taken from U.S. Army ETO (1945), which lists each U.S. division's history of attachments and detachments over its time in the European Theater. For each of the different platoons, companies, troops, squadrons, battalions, and regiments that were attached and detached, the standard numbers of troops were identified from the same sources listed in the previous paragraph.

References

Anderson, Richard C., Jr. "The U.S. Army in World War II." Military History Online, 2000. <<http://www.militaryhistoryonline.com/wwii/usarmy/default.aspx>>

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

Bishop, Chris and Chris McNab. 2003. *The campaigns of World War II day by day*. Hauppauge, NY: Barron's Educational Series.

Brown, John Sloan. *Draftee division*. Lexington, KY: The University Press of Kentucky, 1986.

Copp, J. Terry. 2006. *Cinderella army: the Canadians in Northwest Europe*. Toronto: University of Toronto Press.

Crawford, Richard H. and Cook, Lindsley F. "Procurement." In Whiting, Theodore E., ed., *Statistics*. United States Army in World War II (Green Book Series). Unpublished Manuscript. United States Army Center of Military History, 1953. Center of Military History Library Call No. 2-3.7/AA.W.

Dupuy, Trevor N. 1962. *The military history of World War II: Volume 3, Land Battles: North Africa, Sicily, and Italy*. New York: Franklin Watts, Inc.

Dupuy, Trevor N. *Numbers, prediction, and war*. Fairfax, VA: HERO Books, 1985.

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

Dupuy, Trevor N. *Attrition: Forecasting Battle Casualties and Equipment Losses in Modern War*. Nova Publications. Falls Church, VA. 1995.

Dupuy, Trevor N., David L. Bongard, and Richard C. Anderson, Jr. 1994. *Hitler's last gamble: the battle of the bulge, December 1944-January 1945*. New York: Harper-Collins Publishers.

The Dupuy Institute. "Capture Rate Study Phases I and II Final Report," Produced for Center for Army Analysis. Annandale, VA. March 2000.

Available at: <http://www.dupuyinstitute.org/pdf/e-4epw1and2final.pdf>

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

The Dupuy Institute. *The Historical Combat Effectiveness of Lighter-Weight Armored Forces*. Annandale, VA. August 2001b.

Available at : <http://www.dupuyinstitute.org/pdf/mwa-2lightarmor.pdf>

The Dupuy Institute. *Measuring the Value of Situational Awareness*. Annandale, VA. February 2004.

The Dupuy Institute. "Appendix M: Representativeness of the DLEDB." *Forecast of Future Casualties in Iraq*. Annandale, VA. January 2005.

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

Goldewijk, Klein K., 2001. Estimating global land use change over the past 300 years: The HYDE database, *Global Biogeochemical Cycles* 15(2): 417-433.

Greenfield, Kent R.; Palmer, Robert R. and Wiley, Bell I. *The organization of ground combat troops*. United States Army in World War II (Green Book Series). Washington, DC: Historical Division, Department of the Army, 1947 (reprinted 1987).

Hamilton, William A., Jr. "Construction and Real Estate." In Whiting, Theodore E., ed., *Statistics*. United States Army in World War II (Green Book Series). Unpublished Manuscript. United States Army Center of Military History, 1953. Center of Military History Library Call No. 2-3.7/AA.W.

Hartley, Dean S., III. 2001. *Topics in operations research: predicting combat effects*. Institute for Operations Research and the Management Sciences. Baltimore, MD. 2001.

Note: includes CD with Land Warfare Database

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

Hays, Jack J. *United State Army Ground Forces tables of organization and equipment, World War II, volume 2: The armored division 1940-1945, part 2*. Milton Keynes, England: Military Press, 2004.

Hays, Jack J. *United State Army Ground Forces tables of organization and equipment, World War II, volume 3: The airborne division 1942-1945, part 1*. Milton Keynes, England: Military Press, 2003a.

Hays, Jack J. *United State Army Ground Forces tables of organization and equipment, World War II, volume 3: The airborne division 1940-1945, part 2*. Milton Keynes, England: Military Press, 2003b.

Hays, Jack J. *United State Army Ground Forces tables of organization and equipment, World War II, volume 1: The infantry division 1940-1945, part 1*. Milton Keynes, England: Military Press, 2002.

Helmbold, Robert L. "Combat Analysis." *Phalanx*, Vol. 26, No.3. Military Operations Research Society, Alexandria, VA. September 1993.

Herbert, James K. and Richards, George J. "Notes on Presentation of Requirements Division Before Procurement Review Board: Army Supply Program and Matters Related to Requirements Division." United States. Army Service Forces, 1943. Record Group 160, Entry 94, Box 697 and Entry 88, Box 580. National Archives II Building, College Park, MD. Note: Original presentation by Denson, Lee A. and Wood, Walter A., Jr.

Howe, George F. 1993. *United States Army in World War II: The Mediterranean Theater of Operations: Northwest Africa: seizing the initiative in the West*. Washington, DC: United States Army Center of Military History.

Imbrie, John and Barbara Imbrie. 2004. "Chronology of the 10th Mountain Division in World War II, 6 January 1940 to 30 November 1945." Lakewood, Colorado: National Association of the 10th Mountain Division Association. Available at: <http://10thmtndivassoc.org/chronology.pdf>

Jordan, David and Andrew Wiest. 2004. *Atlas of World War II*. London: Amber Books, Ltd.

Joslen, H.F. 2009. *Orders of battle: United Kingdom and colonial formations and units in the Second World War 1939-1945*. London: Naval and Military Press (new edition of 1960 printing).

Kay, Robin L. 1967. *Official history of New Zealand in the Second World War 1939-45. Italy Volume II: From Cassino to Trieste*. Wellington, New Zealand: R.E. Owen, Government Printer.

Keast, William R. "Training of Officer Candidates in AGF Special Training Schools." Study No. 31. Historical Section, United States Army Ground Forces, 1946. Center of Military History Library Call No. D 769 A5331 no. 31.

Keegan, John. 2006. *Atlas of World War II*. London: Harper-Collins Publishers.

Kurowski, Franz. 1995. *The history of the Fallschirmpanzerkorps Herman Göring*. Winnipeg, Canada: J.J. Fedorowicz Publishing, Inc.

Lawrence, Christopher. "The Second Test of the TNDM Battalion-Level Validations: Predicting Casualties." *The International TNDM Newsletter*. April, 1997.

Available at: <http://www.dupuyinstitute.org/tdipub4.htm>

Lawrence, Christopher A. "The Velocity Attrition Factor." *The International TNDM Newsletter*, October 1996, 1(2), pg. 64.

Llewellyn, Stephen P. 1949. *Official history of New Zealand in the Second World War 1939-45. Journey Towards Christmas: Official History of the 1st Ammunition Company Second New Zealand Expeditionary Force, 1939-1945*. Wellington, New Zealand: War History Branch, Department of Internal Affairs. Printed by Dunedin, New Zealand: Coulls Somerville Wilkie, Ltd.

- Maughan, Barton. 1966. *Australian in the War of 1939-1945: Series 1 – Army, Volume III – Tobruk and El Alamein*.
- McCann, Frank D. 1974. *The Brazilian-American Alliance, 1937-1945*. Princeton, NJ: Princeton University Press.
- McKinney, J.B. 1952. *Official history of New Zealand in the Second World War 1939-45. Medical Units of 2 NZEF in Middle East and Italy*. Wellington, New Zealand: War History Branch, Department of Internal Affairs. Printed by Dunedin, New Zealand: Coulls Somerville Wilkie, Ltd.
- Messenger, Charles. 1989. *The chronological atlas of World War Two*. New York: MacMillan.
- Meyer, Hubert. 2005. *The 12th SS: The history of the Hitler Youth Panzer Division: Volume Two*. Mechanicsburg, PA: Stackpole Books.
- Meyer, Kurt. 2005. *Grenadiers: The story of Waffen SS general Kurt “Panzer” Meyer*. Mechanicsburg, PA: Stackpole Books.
- Mitcham, Samuel W., Jr. 2007a. *German order of battle volume one: 1st-290th Infantry Divisions in WWII*. Mechanicsburg, PA: Stackpole Books.
- Mitcham, Samuel W., Jr. 2007b. *German order of battle volume two: 291st-999th Infantry Divisions, named infantry divisions, and special divisions in WWII*. Mechanicsburg, PA: Stackpole Books.
- Mitcham, Samuel W., Jr. 2007c. *German order of battle volume three: Panzer, Panzer Grenadier, and Waffen SS Divisions in WWII*. Mechanicsburg, PA: Stackpole Books.
- Mitcham, Samuel W., Jr. 2007d. *The Panzer Legions: A guide to the German Army tank divisions of WWII and their commanders*. Mechanicsburg, PA: Stackpole Books.
- Mitcham, Samuel W., Jr. 1985. *Hitler’s legions: the German Army order of battle*. New York: Stein and Day.
- Mitchell, T.D. and Jones, P.D. 2005. “An improved method of constructing a database of monthly climate observations and associated high-resolution grids.” *Int. J. Climatol.* 25: 693 – 712.
- Moraes, Joao Baptista Mascarenhas de. 1966. *Brazilian Expeditionary Force, by its commander*. Translated from 2nd Ed, revised and enlarged. Washington, DC: U.S. Government Printing Office.
- Natkiel, Richard. 2006. *The atlas of World War II*. North Dighton, MA: JG Press, Inc.

Nicholson, Gerald W. L. 1956. *Canadians in Italy 1943-1945*. Ottawa, Canada: Queen's Printer and Controller of Stationery.

Palmer, Robert R.; Wiley, Bell I. and Keast, William R. *The procurement and training of ground combat troops*. United States Army in World War II (Green Book Series). Washington, DC: Historical Division, Department of the Army, 1948 (reprinted 1991).

Partin, John W. "Wars and New Challenges, 1939-1983." In Partin, John W., ed., *A brief history of Fort Leavenworth*. Fort Leavenworth, KS: Combat Studies Institute, United States Army Command and General Staff College, 1983.

Phillips, Neville C. 1957. *Official history of New Zealand in the Second World War 1939-45. Italy Volume I: The Sangro to Cassino*. Wellington, New Zealand: War History Branch, Department of Internal Affairs. Distributed by Christchurch, New Zealand: Whitcombe & Tombs, Ltd.

Pimlott, John. 2006. *The atlas of World War II*. Philadelphia: Running Press.

Rohlf, Chris. "Three Essays Measuring Dollar-Fatality Tradeoffs and Other Human Costs of War." Ph.D. Dissertation, University of Chicago. June 2006.

Rotte, Ralph and Schmidt, Christoph M. "On the Production of Victory: Empirical Determinants of Battlefield Success in Modern War." *Defence and Peace Economics*, June 2003, 14(3), pp. 175-92.

Smith, R. Elberton. *The Army and economic mobilization*. United States Army in World War II (Green Book Series). Washington, DC: Historical Division, Department of the Army, 1959.

Stanton, Shelby L. *Order of battle: U.S. Army, World War II*. Novato, CA: Presidio Press, 1984.

Stone, Bill. 1999. "Free French Divisions." Available at: <http://stonebooks.com/history/freefrench.shtml>, most recently accessed on March 5, 2010.

Terry, Nick and Lowry Cole. 2001a. *German Army, 1939-1945, volume 6: Divisions (Part 1)*. Milton Keynes, United Kingdom: Military Press.

Terry, Nick and Lowry Cole. 2001b. *German Army, 1939-1945, volume 7: Divisions (Part 2)*. Milton Keynes, United Kingdom: Military Press.

United States Airborne in World War II, The. "The U.S. Airborne in World War II." Roll of Honor lists of fatalities by division and regiment. Accessed on January 27th, 2010. Available at: http://www.ww2-airborne.us/division/order_battle.html

U.S. American Battle Monuments Commission. 2005. "ABMC World War II Cemetery Files." Available as a searchable database at: <http://www.abmc.gov/search/wwii.php>. Contact: Martha Sell, ABMC. (703) 696-6897.

U.S. American Graves Registration Service. 1954. "Rosters of Military Personnel Whose Remains Were Not Recovered, 1951-54." Record Group 92, Archives II. Contacts: John Horn, DPMO, John.Horn@osd.mil.

Available in electronic form at: http://www.dtic.mil/dpmo/WWII_MIA/INDEX.HTM

United States. Army Adjutant General. "Army Battle Casualties and Nonbattle Deaths in World War II: Final Report, 7 December 1941-31 December 1946." Statistical and Accounting Branch, 1953. Library Call No. 1954:4728, National Archives II Building, College Park, MD.

United States. Army Air Forces. *Army Air Forces statistical digest of World War II*. Washington, DC: Office of Statistical Control, 1945.

United States. Army Chief of Staff. "Enlisted Men Used in Restricted Activities." Security Classified General Correspondence, 1944-45: 200, Case I, 1945a. Record Group 165, Entry 13, Box 150. National Archives II Building, College Park, MD.

United States. Army Chief of Staff. "Estimated Army Ground Forces Zone of the Interior Requirements." Security Classified General Correspondence, 1944-45: 200.3, Cases 32-75, 1945b. Record Group 165, Entry 13, Box 151. National Archives II Building, College Park, MD.

United States. Army Chief of Staff. "Quarterly Estimates of Personnel to Operate the Zone of the Interior Establishment." Security Classified General Correspondence, 1944-45: 200.3, Cases 32-75, 1945c. Record Group 165, Entry 13, Box 151. National Archives II Building, College Park, MD.

United States. Army Chief of Staff. "Summary of War Department Manpower Board Survey of Army Ground Forces Schools." Security Classified General Correspondence, 1944-45: 200.3, Case 75, 1945d. Record Group 165, Entry 13, Box 151. National Archives II Building, College Park, MD.

United States. Army European Theater of Operations (ETO). 1945. *Order of battle of the United States Army World War II European Theater of Operations*. Office of the Theater Historian, Paris France.

Available at: <http://www.history.army.mil/documents/eto-ob/ETOOB-TOC.htm>

United States. Army Ground Forces. "Incidental Expenses of the Army, 440 – Ground Force Activities." Headquarters, Army War College, circa 1945. Record Group 337, Entry 51, Box 2. National Archives II Building, College Park, MD.

United States. Army Ground Forces. "Monthly Report of Lend-Lease Charges for Chinese Officers Training Program." Chief of Finance, May 1947. Record Group 337, Entry 51, Box 11, National Archives II Building, College Park, MD.

United States. Army Office of the Comptroller. "Estimated Annual Per Capita Cost of Enlisted Personnel, by Grade." Public Relations and Affairs Division, 1953. Center of Military History Library Call No. Misc. 121.6. Note: Contained in miscellaneous cost folder.

United States. Army Service Forces. "Army Supply Program: Section 1: Equipment, Ground." Statistical Unit, April 6, 1942a (Box 704); September 1, 1942b (Box 704); August 1, 1943a (Extract of Engineer Corps, Box 704); August 1, 1943b. (Box 705); February 1, 1943c (Extract of Engineer Corps, Box 704); February 1, 1944a (Box 706). Record Group 160, Entry 94. National Archives II Building, College Park, MD.

United States. Army Service Forces. "A.S.F. Logistical Planning and Reference Data." Planning Division, General Staff Corps, July 1943d. Record Group 160, Entry 94, Box 686. National Archives II Building, College Park, MD.

United States. Army Service Forces. "Data on Cost of Equipping and Maintaining a Soldier for One Year." Budgetary Control Sub-Section, Procurement Section, Clothing and Equipage Branch, Supply Division, Office of the Quartermaster General, 1944b. Center of Military History Library Call No. HRC 121.6.

United States. Army Service Forces. "Replacement Factors." Requirements Division, December 15, 1943e; June 15, 1944c and December 15, 1944d. Record Group 160, Entry 94, Box 699. National Archives II Building, College Park, MD.

United States. Army Service Forces. "Statistical Review, World War II: A Summary of ASF Activities." Statistics Branch, Control Division, circa 1954. Record Group 160, Entry 94, Box 702. National Archives II Building, College Park, MD.

United States. Army Service Forces Office of the Quartermaster General. *Data on Cost of Equipping and Maintaining a Soldier for One Year*. Budgetary Control Sub-Section, Procurement Section, Clothing and Equipage Branch, Supply Division, Office of The Quartermaster General, Army Service Forces, War Department. Washington, DC. 1944. CMH Library Call Number HRC 121.6.

United States. Army Services of Supply. "Monthly Status Report Number, Equipment Section, Army Supply Program." Statistics and Progress Branch, Control Division, August 1942a and October 1942b. Record Group 160, Entry 94, Box 710. National Archives II Building, College Park, MD.

United States. Army Services of Supply. "Contributions of the Services of Supply to an Armored, a Motorized, and an Infantry Division of the Army of the U.S." Statistics and Progress Branch, Control Division, 1943. Record Group 160, Entry 94, Box 716, National Archives II Building, College Park, MD.

United States. Bureau of the Budget. *The budget of the United States government*. Washington, DC: United States Government Printing Office, 1940 to 1947.

United States. Bureau of Labor Statistics. "Prices of Specific Items," Consumer Price Index Statistics, 2004. <<http://www.bls.gov/cpi/#data>>

United States. Congress. "An Act to Provide for the Payment of Six Months' Pay to the Widow, Children, or Other Designated Dependent Relative of any Officer or Enlisted Man of the Regular Army whose Death Results from Wounds or Disease not the Result of his Own Misconduct." Statutes at Large, 66th Congress, 2nd Session. Chapter 6, 41 Statute 367, December 17, 1919.

United States. Congress. "Pay Readjustment Act of 1942." Statutes at Large, 77th Congress, 2nd Session. Chapter 413, 56 Statute 359, June 16, 1942.

United States. Congress. "Amendment to the Pay Readjustment Act of 1942." Statutes at Large, 79th Congress, 2nd Session. Chapter 523, 60 Statute 343, June 29, 1946.

United States. Defense Finance and Accounting Service. "Military Pay Prior Rates," 2006. <http://www.dod.mil/dfas/militarypay/2006militarypaytables/militarypay_piorrates.html>

U.S. Geological Survey. 2005. "Shuttle Radar Topography Mission (SRTM) 'Finished' 3 Arc Second (~90 Meter)." Available at: <http://seamless.usgs.gov/products/srtm3arc.php#download>

U.S. National Archives and Records Administration. 2002. "Electronic Army Serial Number Merged File, ca. 1938-1946 (*Enlistment Records*)." Office of Records Services, Electronic and Special Media Records Division. Series from Record Group 64. Available as a searchable database at: <http://aad.archives.gov/aad/fielded-search.jsp?dt=893&cat=WR26&tf=F&bc=,sl>. Contact: Lee Gladwin, NARA, (301) 837-0470.

United States. National Geospatial-Intelligence Agency. "GEONet Names Server (GNS)," 2006. <http://earth-info.nga.mil/gns/html/gis_contryfiles.html>

U.S. Navy 1946. "State Summaries of War Casualties from World War II for Navy, Marine Corps, and Coast Guard Personnel." Office of Public Information, Casualty Section, Bureau of Naval Personnel. Record Group 24, Archives II. Contact: Mike Conley, ABMC. (703) 696-6778. Available in pdf format at: <http://www.archives.gov/research/arc/ww2/navy-casualties/index.html> and as a searchable database at: <http://www.wwiimemorial.com/default.asp?page=registry.asp>

U.S. War Department. 1944. "Listing of All Battle Casualties, Officers and Enlisted Men by State, County, and Type of Casualty as Reported to Machine Records Branch – Books I to V (From 7 Dec. 1941 through 31 Dec. 1943)." Machine Records Branch, Adjutant General's Office. Tabulation No. CFN-8. Record Group 407.2.4, Archives II.

U.S. War Department. 1946. "World War II Honor List of Dead and Missing Army and Army Air Forces Personnel." Strength Accounting Branch, Administrative Services Division, Adjutant General's Office. Record Group 407.2.4, Archives II. Contact: Mike Conley, ABMC. (703) 696-6778.

Available in pdf format at: <http://www.archives.gov/research/arc/ww2/army-casualties/> and as a searchable database at: <http://www.wwiimemorial.com/default.asp?page=registry.asp>

U.S. War Department. 1947. "Chemical Warfare Service Personnel Who Died During World War II 7 December 1941 Through 30 June 1946." Statistics and Reports Section, Strength Accounting Branch, Adjutant General's Office. Tabulation No. CFN-140. Record Group 407.2.4, Archives II. Note: These records are filed as deaths of Chemical Warfare Service personnel (Tabulation No. CFN-140). However, the folders include many other casualty lists (with different tabulation numbers) that are labeled in the files as alphabetical listings of battle deaths for each division.

United States. War Department Bureau of the Budget. "Estimated Cost of H.R. 5041, *Armed Forces Leave Act of 1946*." Special Staff, Budget Division, General Records, 1946. Record Group 165, Entry 455, Box 23. Security Classified General Correspondence, 1942-1947. Decimal 0.32.1. National Archives II Building, College Park, MD.

United States. War Department Office of the Budget Officer. "Additions to Revised Estimates, Fiscal Year 1943," 1943. Record Group 337, Entry 51, Box 2, File No. SPBFO 3020. National Archives II Building, College Park, MD.

United States. War Department Public Relations Division. "Cost of Equipping, Maintaining Soldier for One Year Rises 10.7 Percent Since 1945." Press Section, 1946. Center of Military History Library Call No. Misc. 121.6.

Von Luck, Hans. 1989. *Panzer commander: the memoirs of Colonel Hans von Luck*. New York: Dell Publishing.

Von Mellenthin, F.W. 1956. *Panzer battles*. Old Saybrook, CT: Konecky & Konecky.

Wikipedia, 2010a. "Military History of Australia During World War II." http://en.wikipedia.org/wiki/Military_history_of_Australia_during_World_War_II, most recently accessed on March 5, 2010.

Wikipedia, 2010b. "Military History of Canada During World War II." http://en.wikipedia.org/wiki/Military_history_of_Canada_during_the_Second_World_War, most recently accessed on March 5, 2010.

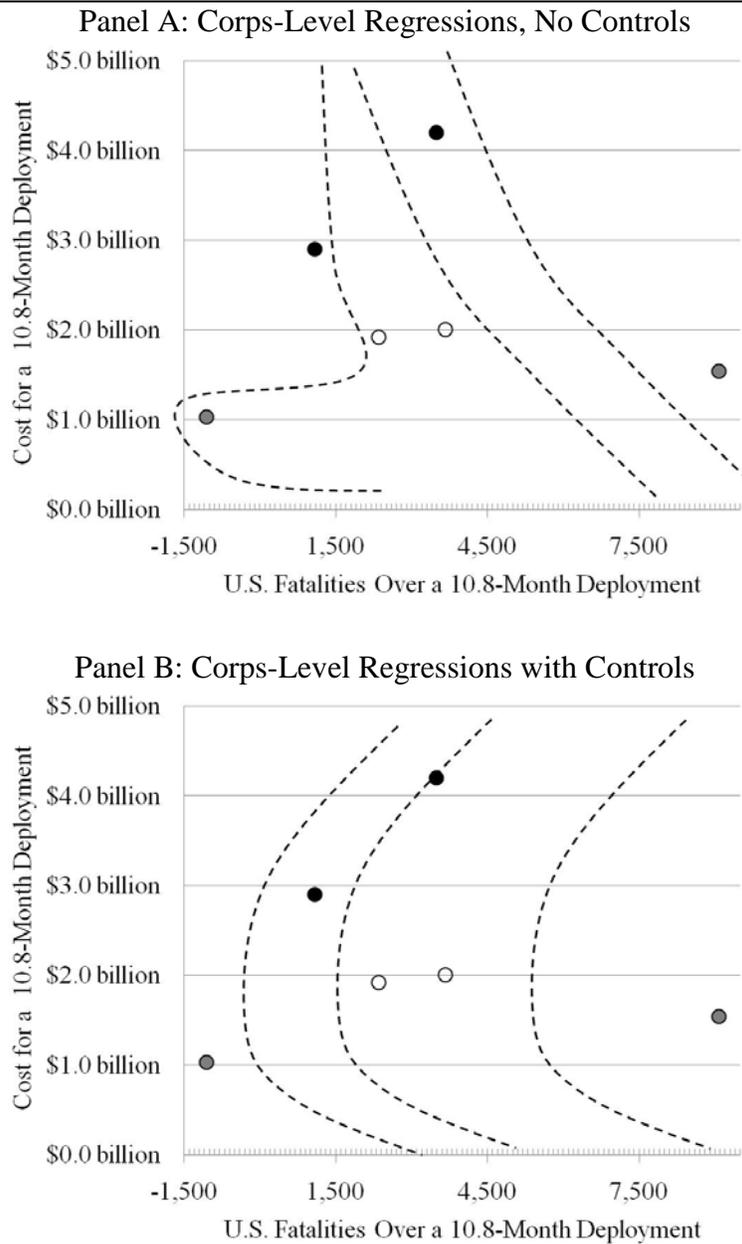
Wikipedia, 2010c. "Military History of France During World War II." http://en.wikipedia.org/wiki/Military_history_of_France_during_World_War_II, most recently accessed on March 5, 2010.

Wikipedia, 2010d. "Military History of New Zealand During World War II." http://en.wikipedia.org/wiki/Military_history_of_New_Zealand_during_World_War_II, most recently accessed on March 5, 2010.

Wilson, John B. *Maneuver and firepower*. United States Army Center of Military History. Washington, DC: United States Government Printing Office, 1998.

Zetterling, Niklas. 2000. *Normandy, 1944: German military organization, combat power, and organizational effectiveness*. Winnipeg, Canada: J.J. Fedorowicz Publishing, Inc.

Figure A1: Estimated Costs, Fatalities, and Military Production Isoquants by Division Type, Estimates from Corps-Level Regressions



Notes to Figure A1: These figures are the corps-level counterparts to those shown in Figure 3. The fatality and km figures are the coefficients on the number of divisions of that type in each corps that day. Sample includes corps days in which one or more Axis divisions were in same the cell as the average division in that corps. Additional details in the text.

Figure A2: Mission Accomplishment Worksheet for Dupuy Institute Databases

Engagement name: _____

Engagement date: _____

Assessment date: _____

Assessor's Initials: _____

Attacker

Defender

Unit: _____

Unit: _____

Conceptual Accomplishment: 0
1
2

Conceptual Accomplishment: 0
1
2

Geographical Accomplishment: 0
1
2

Geographical Accomplishment: 0
1
2

Block Hostile Missions: 0
1
2

Block Hostile Mission: 0
1
2

Command & Staff Performance: 0
1
2

Command & Staff Performance: 0
1
2

Troop Performance: 0
1
2

Troop Performance: 0
1
2

Bonus or Penalty:
Explain:

Bonus or Penalty:
Explain:

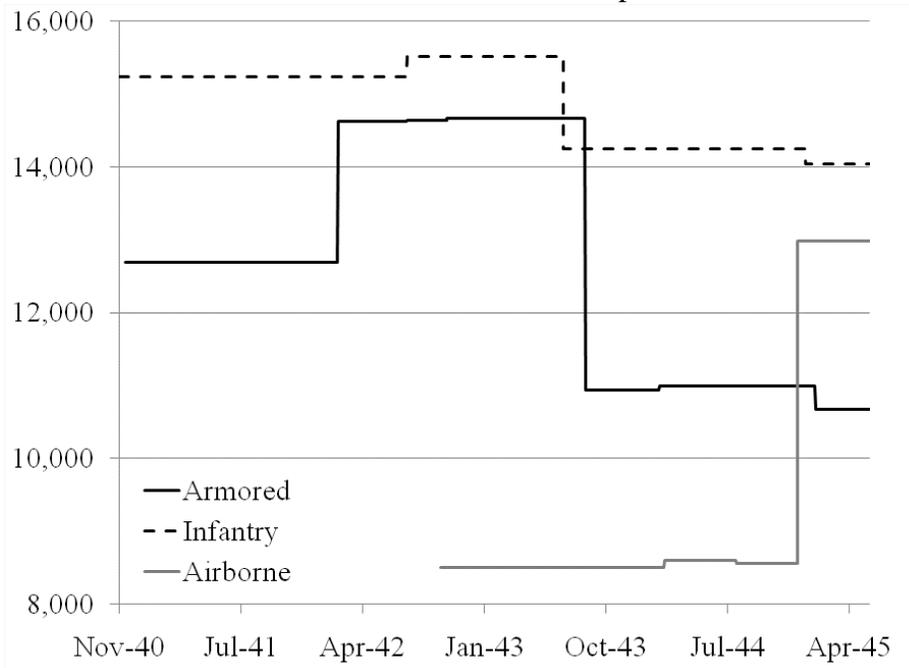
Total Score: _____

Total Score: _____

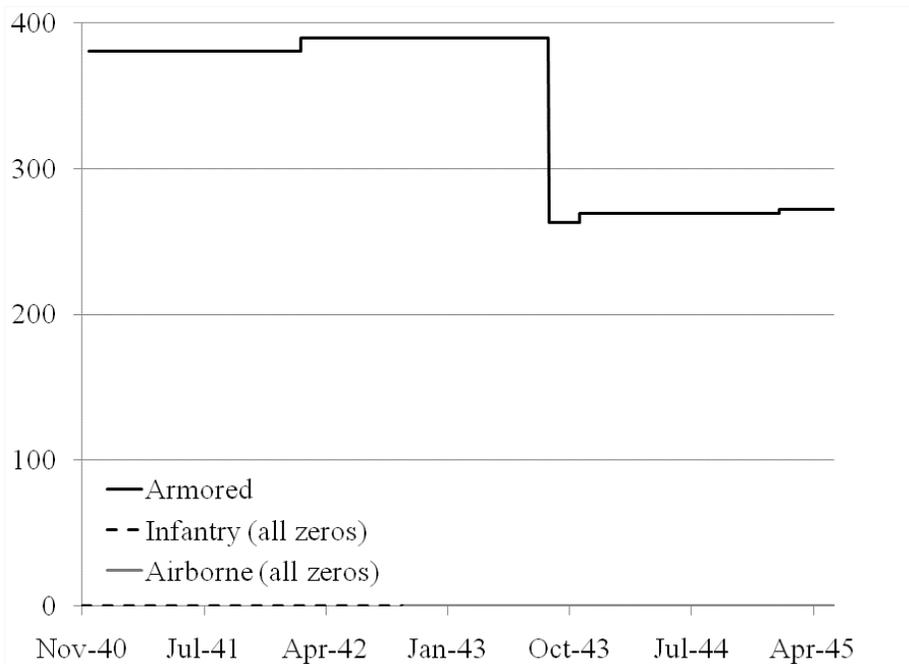
Notes to Figure A2: The 0-1 index of U.S. Mission Accomplishment used in this study is calculated as the (U.S. Total Score – German Total Score)/16. Source: The Dupuy Institute (2001a).

Figure A3: Numbers of Troops and Tanks in an Organic U.S. Army Armored, Infantry, and Airborne Division, 1940-1945

Panel A: Numbers of Troops



Panel B: Numbers of Tanks



Notes to Figure A3: “Organic” indicates the numbers specified in the U.S. Army Tables of Organization and Equipment and ignores attached or detached battalions, combat losses, and replacement troops. Sources: Hays (2002, 2003a, 2003b, 2004).

Table A3: Estimated Combat Outcomes and Costs Over a 10.8-Month Deployment by Division Type

Division Type and Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Division by Day Panel				Engagement Data			
	Axis Divisions in Cell ≥ 1		U.S. KIA ≥ 5		By Division Type		Troop & Tank Regressions	
Pre-Reorganization								
Armored Division								
1. Km Advanced	1.929	1.802	3.384	2.964	0.978	1.146	1.994	2.089
2. Mission Success					0.764	0.699	0.692	0.626
3. U.S. Deaths	1,059	834.0	1,346	1,255	2,297	-500.7	2,624	561.4
4. Cost (billions)	\$4.20	\$4.20	\$4.20	\$4.20	\$5.14	\$5.14	\$4.20	\$4.20
Infantry Division								
5. Km Advanced	1.058	0.768	1.513	2.946	0.587	0.436	0.572	0.596
6. Mission Success					0.510	0.607	0.520	0.547
7. U.S. Deaths	2,120	1,692	1,796	1,581	1,453	3,543	1,640	2,294
8. Cost (billions)	\$1.92	\$1.92	\$1.92	\$1.92	\$2.20	\$2.20	\$1.92	\$1.92
Airborne Division								
9. Km Advanced	1.985	2.222	-0.021	0.105			0.460	0.427
10. Mission Success							0.489	0.448
11. U.S. Deaths	3,948	2,935	2,302	1,982			1,436	2,024
12. Cost (billions)	\$1.03	\$1.03	\$1.03	\$1.03			\$1.03	\$1.03
Post-Reorganization								
Armored Division								
13. Km Advanced	1.706	1.931	3.699	3.407	1.923	2.980	1.758	2.073
14. Mission Success					0.569	0.573	0.648	0.572
15. U.S. Deaths	1,116	1,326	1,225	1,160	2,311	-1,011	2,266	768
16. Cost (billions)	\$2.90	\$2.90	\$2.90	\$2.90	\$2.93	\$2.93	\$2.90	\$2.90
Infantry Division								
17. Km Advanced	1.072	1.086	1.848	1.720	1.228	1.116	0.656	0.683
18. Mission Success					0.590	0.481	0.529	0.544
19. U.S. Deaths	1,822	1,904	1,839	1,901	1,967	613	1,685	2,157
20. Cost (billions)	\$2.00	\$2.00	\$2.00	\$2.00	\$2.29	\$2.29	\$2.00	\$2.00
Airborne Division								
21. Km Advanced	1.574	1.472	0.874	1.764	-2.090		0.579	0.598
22. Mission Success					0.613		0.512	0.501
23. U.S. Deaths	2,284	1,837	2,352	1,950	4,513		1,570	2,091
24. Cost (billions)	\$1.54	\$1.54	\$1.54	\$1.54	\$2.49	\$2.49	\$1.54	\$1.54
Controls?		Yes		Yes		Yes		Yes

Notes to Table A3: Estimates are the same as those presented in graphical form in the main text.

Table A4: Cost per Life Saved and Lives Saved from Effectiveness-Neutral Combinations of Policies

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Division by Day Panel				Engagement Data			
	Axis Divisions in Cell ≥ 1		U.S. KIA ≥ 5		By Division Type		Troop & Tank Regressions	
Replace Infantry with Armored plus Partial Armored Reorganization								
Cost per Life Saved (millions of 2009 dollars)	-\$3.328 (22.58)	\$2.643 (1.212)**	-\$37.26 (324.2)	\$7.224 (18.19)	-\$0.119 (0.534)	\$0.424 (0.429)	-\$10.21 (24.69)	\$0.394 (0.900)
Lives Saved	837.1 (1,015)	4,807 (26,666)	-267.9 (3,231)	322.7 (334.0)	-577.5 (907.8)	3,030 (805.6)	271.2 (653.7)	966.4 (565.4)*
Infantry Reorganization plus Partial Replace Infantry with Armored								
Cost per Life Saved (millions of 2009 dollars)	\$0.210 (1.606)	\$0.601 (1.128)	\$0.533 (1.925)	\$3.355 (5.506)	-\$2.072 (4.356)	\$0.262 (0.099)**	-\$6.832 (80.72)	\$0.927 (0.493)*
Lives Saved	281.4 (475.9)	-430.0 (614.9)	-154.0 (332.5)	218.2 (516.1)	-1,217 (2,536)	3,538.2 (1,154)**	-2.371 (27.97)	206.4 (319.5)
Replace Infantry with Airborne plus Partial Airborne Reorganization								
Cost per Life Saved (millions of 2009 dollars)	\$0.134 (0.631)	\$0.109 (0.811)	\$0.029 (2.305)	\$0.053 (2.107)			-\$15.13 (138.7)	\$0.631 (0.452)
Lives Saved	1,930 (8,069)	885.7 (2,561)	-592.7 (558.6)	-346.2 (506.1)			12.15 (111.4)	98.58 (53.46)*
Infantry Reorganization plus Replace Infantry with Airborne								
Cost per Life Saved (millions of 2009 dollars)	\$0.300 (0.787)	-\$1.720 (5.878)	\$0.357 (1.229)	\$7.608 (38.69)	-\$0.110 (0.062)*		-\$18.79 (260.2)	\$1.359 (0.775)*
Lives Saved (millions of 2009 dollars)	351.0 (1,423)	815.2 (3,073)	-216.8 (515.6)	-11,284 (171,851)	5,745 (9,467)		7.796 (108.3)	86.86 (47.13)*
Replace Airborne with Armored plus Partial Armored Reorganization								
Cost per Life Saved (millions of 2009 dollars)	\$1.201 (2.127)	-\$2.144 (88.25)	-\$48.99 (632.6)	\$96.79 (2,150)			-\$9.203 (18.14)	-\$1.964 (2.629)
Lives Saved (millions of 2009 dollars)	2,904 (285.3)**	497.8 (9,256)	-350.9 (5,738)	119.4 (2,395)			304.3 (594.1)	563.7 (514.7)
Airborne Reorganization plus Partial Replace Airborne with Armored								
Cost per Life Saved (millions of 2009 dollars)	\$1.205 (0.680)*	\$4.385 (8.436)	-\$0.197 (3.849)	\$0.772 (1.374)			-\$22.66 (330.2)	\$0.716 (0.472)
Lives Saved	3,942 (20,730)	622.1 (1,825)	-400.1 (1,104)	-1,118 (1,597)			-12.51 (182.3)	-704.7 (589.9)
Controls?	Yes		Yes		Yes		Yes	

Notes to Table A4: Each cost per life saved estimates the cost of implementing one of the policies suggested plus partially implementing the second one the exact fraction of the amount necessary to hold success constant (measured as km success in the division by day data and the subjective index in the engagement data). Details in the text.

Table A5: OLS and Fixed Effects Estimates of the First Stage Effects of Division Type on Kilometers of Progress and U.S. KIA, Division by Day Panel

Division Type	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Panel A: Dependent Variable is Kilometers of Progress Toward Berlin/Tunis/Messina									
	Division Days in Which Axis Divisions in Cell ≥ 1					Division Days in Which U.S. KIA ≥ 5				
	Full Sample			Full Sample			Full Sample			
Post-Reorganization	-0.156	0.129	0.502	-5.245	-4.351	0.245	0.443	0.923	22.41	1.281
* Armored	(0.658)	(0.677)	(0.743)	(4.285)	(4.257)	(0.820)	(0.834)	(0.837)	(10.13)**	(15.03)
Post-Reorganization	0.169	0.319	0.062	-0.707	-2.961	-0.513	-1.226	0.886	2.844	2.940
* Infantry	(0.642)	(0.693)	(0.888)	(0.987)	(1.149)**	(0.809)	(0.894)	(1.135)	(1.410)**	(1.796)
Post-Reorganization	-0.273	-0.751	-0.654	13.58		1.469	1.659	0.164	-51.67	71.00
* Airborne	(1.849)	(1.986)	(1.814)	(21.44)		(2.573)	(2.688)	(2.346)	(38.39)	(27.64)**
Armored	0.943	1.035	1.176	-2.451		0.968	0.018	0.499	-1.112	
	(0.762)	(0.796)	(1.061)	(1.356)*		(0.955)	(1.005)	(1.254)	(1.777)	
Airborne	1.065	1.455	1.286			-2.536	-2.841	1.802	-34.75	
	(1.895)	(2.044)	(1.923)			(2.587)	(2.723)	(2.452)	(27.20)	
R ²	0.003	0.025	0.357	0.649	0.657	0.007	0.031	0.579	0.773	0.773
Panel B: Dependent Variable is U.S. Fatalities										
Post-Reorganization	5.914	7.333	-2.505	20.05	19.03	2.255	-1.357	1.500	11.88	21.59
* Armored	(4.051)	(4.087)*	(4.948)	(45.06)	(45.27)	(2.369)	(2.406)	(3.279)	(48.09)	(71.21)
Post-Reorganization	-0.424	3.160	-26.61	-23.58	-30.29	7.736	4.617	-9.011	-1.246	-2.957
* Infantry	(3.951)	(4.184)	(5.917)**	(10.38)**	(12.21)**	(2.336)**	(2.578)*	(4.449)**	(6.695)	(8.510)
Post-Reorganization	-29.80	-16.37	-14.39	-14.82		-4.146	-0.457	-12.173	289.2	96.18
* Airborne	(11.38)**	(11.99)	(12.08)	(225.4)		(7.433)	(7.754)	(9.195)	(182.3)	(131.0)
Armored	-17.02	-12.78	-37.97	-42.93		-2.197	-4.707	-18.043	-9.918	
	(4.689)**	(4.810)**	(7.068)**	(14.26)**		(2.760)	(2.899)	(4.916)**	(8.439)	
Airborne	30.44	18.52	-4.466			15.77	5.773	-2.426	-79.12	
	(11.66)**	(12.35)	(12.81)			(7.472)**	(7.854)	(9.613)	(129.1)	
R ²	0.054	0.108	0.285	0.466	0.467	0.038	0.070	0.248	0.335	0.340
Controls?		Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes
Month & Year Fes			Yes	Yes	Yes			Yes	Yes	Yes
Axis Division Fes			Yes	Yes	Yes			Yes	Yes	Yes
Cell Fes			Yes	Yes	Yes			Yes	Yes	Yes
U.S. Division Fes					Yes					Yes
N (Division Days)		4,430		1,137			4,579		1,221	
Clusters (Division Months)		470		115			516		137	

Notes to Table A5: Within each panel, each column shows results from a different OLS or fixed effects regression. These regressions represent the first-stage estimates preceding the 2SLS estimates shown in Table 1 of the paper. Additional details in the text.

Table A6: OLS Estimates of the First-Stage Effects of Division Type on Combat Outcomes, Engagement Data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Dependent Variable is . . .											
Variable	Km Progress Along Axis of Advance		Zero to One Index of Mission Success		Indicator for U.S. Success (Draw = 0.5)		U.S. KIA		U.S. Tank Losses		German KIA	
Post-Reorganization * Armored	0.426 (1.160)	1.852 (2.129)	-0.198 (0.036)**	-0.111 (0.089)	-0.209 (0.096)**	-0.140 (0.323)	4.294 (12.01)	-9.452 (11.53)	-4.918 (7.850)	-9.689 (4.290)**	4.935 (24.65)	-2.893 (27.10)
Post-Reorganization * Infantry	-0.460 (0.420)	0.506 (0.736)	-0.023 (0.071)	-0.115 (0.046)**	0.114 (0.163)	-0.235 (0.153)	-7.083 (7.373)	-31.03 (5.427)**	3.346 (2.949)	0.979 (3.589)	-10.42 (9.263)	-20.99 (12.61)*
Armored	-0.821 (1.027)	0.562 (1.402)	0.133 (0.072)*	0.087 (0.085)	0.299 (0.170)*	0.186 (0.320)	-7.121 (12.36)	-33.37 (10.53)**	13.37 (7.489)*	14.85 (4.828)**	8.966 (22.67)	-13.68 (22.62)
Controls Include . . .												
Date & Continent	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Enemy Inputs		Yes		Yes		Yes		Yes		Yes		Yes
Terrain & Weather		Yes		Yes		Yes		Yes		Yes		Yes
Human Factors		Yes		Yes		Yes		Yes		Yes		Yes
R ²	0.076	0.453	0.186	0.597	0.144	0.514	0.083	0.531	0.383	0.649	0.231	0.482
N (Division Days)	279	279	279	279	279	279	279	279	215	215	279	279
Clusters (Engagements)	152	152	152	152	152	152	152	152	118	118	152	152

Notes to Table A6: Within each panel, each column shows results from a different OLS regression. The regressions in columns (1) to (4) (and scaled versions of the regressions in columns (7) and (8)) represent the first-stage estimates preceding the 2SLS estimates shown in the first few columns of Table 2 of the paper. Additional details in the text.

Table A7: OLS and Fixed Effects Estimates of the First Stage Effects of Troops and Tanks, Engagement Data

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: Dependent Variable is Km of Progress					
	Full Sample		Fixed Effects Sample			
U.S. Troops/10,000	0.204 (0.444)	-0.010 (0.568)	-0.278 (0.526)	0.078 (0.513)	-0.208 (0.724)	-1.706 (1.393)
U.S. Tanks/100	0.714 (0.688)	1.169 (0.800)	1.688 (1.246)	2.065 (1.550)	2.093 (1.126)*	1.338 (1.408)
U.S. Troops * U.S. Tanks/1,000,000	-0.231 (0.232)	-0.404 (0.294)	-0.503 (0.413)	-0.486 (0.390)	-0.602 (0.374)	-0.026 (0.288)
R ²	0.043	0.468	0.113	0.452	0.611	0.783
Panel B: Dependent Variable is Zero to One Index of Mission Success						
U.S. Troops/10,000	0.033 (0.032)	0.127 (0.046)**	0.013 (0.033)	0.051 (0.036)	0.118 (0.060)*	0.179 (0.082)**
U.S. Tanks/100	0.072 (0.027)**	0.085 (0.037)**	0.056 (0.047)	-0.070 (0.060)	0.085 (0.062)	-0.047 (0.090)
U.S. Troops * U.S. Tanks/1,000,000	-0.020 (0.010)*	-0.032 (0.014)**	-0.013 (0.015)	0.015 (0.017)	-0.033 (0.024)	-0.009 (0.030)
R ²	0.187	0.594	0.143	0.579	0.542	0.749
Panel C: Dependent Variable is U.S. KIA						
U.S. Troops/10,000	1.556 (6.600)	2.949 (7.227)	0.185 (8.813)	-15.09 (5.741)**	8.066 (9.19)	23.12 (9.527)**
U.S. Tanks/100	1.135 (6.152)	-5.324 (5.925)	13.39 (10.48)	19.94 (13.54)	7.833 (7.883)	-5.359 (9.647)
U.S. Troops * U.S. Tanks/1,000,000	-0.053 (2.409)	0.763 (2.413)	-3.832 (3.596)	-3.750 (3.379)	-4.198 (3.046)	-3.388 (2.794)
R ²	0.077	0.436	0.105	0.386	0.509	0.638
Controls Include . . .						
Date & Continent	Yes	Yes	Yes	Yes	Yes	Yes
Enemy Inputs		Yes			Yes	Yes
Terrain & Weather		Yes			Yes	Yes
Human Factors		Yes			Yes	Yes
Axis Division Fes				Yes		Yes
U.S. Division Fes				Yes		Yes
N (Division Days)	289	289	225	225	225	225
Clusters (Engagements)	162	162	132	132	132	132

Notes to Table A7: Within each panel, each column shows results from a different OLS or fixed effects regression. These regressions represent the first-stage estimates preceding the 2SLS estimates shown in the last few columns of Table 2 of the paper. Additional details in the text.

Table A8: Corps by Day-Level 2SLS Estimates of the Cost Function for Military Operations, Collapsed Division by Day Panel

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Dependent Variable is Estimated Dollar Cost per Day in Millions of 2009 Dollars											
All Division Type Indicators are Excluded Instruments						Armored and Airborne Indicators are Only Excluded Instruments					
Variable	Full Sample				Fixed Effects Sample		Full Sample				Fixed Effects Sample
Km of Progress	10.23 (10.26)	-3.464 (3.970)	9.562 (6.524)	3.090 (2.538)	0.542 (0.350)	0.077 (0.068)	47.69 (86.69)	-10.84 (12.15)	19.90 (25.10)	53.65 (204.5)	-15.01 (30.05)
U.S. Fatalities	-0.294 (0.207)	-0.043 (0.090)	-0.213 (0.317)	-0.075 (0.119)	-0.076 (0.066)	0.001 (0.003)	-0.851 (1.399)	-0.091 (0.233)	-1.046 (1.776)	0.521 (3.206)	-0.236 (0.691)
Controls?		Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes
Month & Year FEs			Yes	Yes	Yes	Yes			Yes	Yes	Yes
Axis Division FEs			Yes	Yes	Yes	Yes			Yes	Yes	Yes
Cell FEs			Yes	Yes	Yes	Yes			Yes	Yes	Yes
U.S. Corps FEs				Yes	Yes	Yes				Yes	Yes
U.S. Division FEs						Yes					
N (Corps Days)		1,024				801			1,024		801
Clusters (Corps Months)		119				93			119		93

Notes to Table A8: Each column shows results from a different corps by day-level 2SLS regression. The specifications are the same as in Table 1, except that the data are organized at the corps by day level, the total number of divisions in the corps is a control variable, and the nearby Allied unit controls are replaced with controls for the other Allied units in the corps. Additional details in the text.

Table A9: 2SLS Estimates of the Cost Function for Military Operations with Alternative Clustering, Division by Day Panel

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent Variable is Estimated Dollar Cost per Day in Millions of 2009 Dollars							
Panel A: Division Days in Which Axis Divisions in Cell ≥ 1							
Variable	Full 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	8.408	-15.06	8.207	0.423	-27.69
(by division month)	(12.20)	(9.057)	(9.157)	(21.01)	(10.50)	(4.939)	(128.7)
(by corps month)	(14.57)	(10.91)	(9.966)	(21.68)	(11.08)	(5.667)	(166.4)
(by division)	(14.48)	(9.913)	(8.119)	(13.13)	(8.943)	(4.143)	(84.77)
U.S. Fatalities	-1.436	-1.926	-1.428	0.048	-1.475	-1.637	-4.371
(by division month)	(0.583)**	(0.625)**	(0.768)*	(2.464)	(0.615)**	(0.576)**	(12.31)
(by corps month)	(0.764)*	(0.856)**	(0.854)*	(2.803)	(0.668)**	(0.600)**	(15.98)
(by division)	(0.679)**	(0.631)**	(0.637)**	(1.661)	(0.515)**	(0.422)**	(8.156)
N (Division Days)	4,430		4,107	3,689	1,064	598	3,832
Corps Months	226		204	215	136	54	204
Divisions	63		60	47	19	10	61
Panel B: Division Days in Which U.S. KIA ≥ 5							
Km of Progress	6.955	-18.58	-80.49	7.891	33.66	-0.846	-22.39
(by division month)	(7.509)	(27.46)	(338.1)	(8.692)	(94.89)	(11.65)	(95.47)
(by corps month)	(7.966)	(27.94)	(350.2)	(8.688)	(89.54)	(11.61)	(142.2)
(by division)	(7.952)	(24.24)	(290.3)	(3.774)**	(63.05)	(11.77)	(89.81)
U.S. Fatalities	-0.711	-4.673	-14.48	-0.014	2.068	-4.956	-4.849
(by division month)	(1.202)	(4.587)	(53.23)	(1.141)	(10.44)	(5.268)	(15.15)
(by corps month)	(1.384)	(4.712)	(55.18)	(1.348)	(9.982)	(5.416)	(22.94)
(by division)	(1.256)	(4.241)	(46.88)	(1.094)	(6.843)	(3.995)	(14.28)
Controls?		Yes	Yes	Yes	Yes	Yes	Yes
N (Division Days)	4,579		4,395	3,841	922	621	3,958
Corps Months	224		204	216	126	65	194
Divisions	64		61	49	18	10	62

Notes to Table A9: This table reproduces estimates from Table 1 but with varying ways of clustering the standard errors. Additional details in the text.

Table A10: 2SLS Estimates of the Cost Function for Military Operations with Alternative Clustering, Engagement Data

	(1)	(2)	(3)	(4)	(6)	(8)	(10)	(12)
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 Progress	-1,411	558.1	-721.6	21.73	48.58	279.6	1,051	-961.2
(by engagement)	(3,449)	(594.2)	(1,425)	(58.19)	(1,220)	(127.9)**	(2,009)	(2,265)
(by division)	(3,277)	(717.9)	(1,248)	(56.86)	(992.0)	(90.14)**	(1,812)	(2,611)
U.S. Fatalities	2.571	-0.833	-0.595	-0.080	4.721	0.286	6.942	4.727
(by engagement)	(13.61)	(1.414)	(1.833)	(0.178)	(7.808)	(1.006)	(17.58)	(12.46)
(by division)	(11.54)	(1.272)	(2.512)	(0.191)	(9.280)	(0.805)	(12.41)	(14.79)
Panel B: Mission Effectiveness Measured with Zero to One Index								
Zero to One Index	2,995	-760.4	2,296	4,053	578.0	5,487	7,194	13,757
(by engagement)	(872.7)**	(2,570)	(925.9)**	(1,562)**	(13,561)	(10,558)	(4,246)*	(9,711)
(by division)	(1,045)**	(3,366)	(1,171)*	(1,259)**	(11,275)	(14,033)	(4,489)	(12,360)
U.S. Fatalities	0.422	-1.270	-0.309	-0.142	4.506	-1.468	-0.035	-1.505
(by engagement)	(1.251)	(1.696)	(0.592)	(0.379)	(12.12)	(4.114)	(1.823)	(3.879)
(by division)	(1.458)	(2.736)	(0.763)	(0.399)	(12.40)	(5.372)	(1.634)	(4.978)
Controls Include . . .								
Date & Continent	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sorties & Enemy Inputs		Yes						
Terrain & Weather			Yes					
Human Factors				Yes				
N (Division Days)	279	279	279	279	289	150	139	225
Divisions	19	19	19	19	20	13	16	15

Notes to Table A10: This table reproduces estimates from Table 2 but with varying ways of clustering the standard errors. Additional details in the text.

Table A11: 2SLS Estimates of the Cost Function for Military Operations with Alternative Specifications, Engagement Data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
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	Benchmark, Excluding Airborne	Excluding Cases with U.S. as Defender		Excluding Cases with Axis Aerial Sorties		Light & Heavy Tanks Treated Separately	Benchmark, Full Sample	Excluding Cases with U.S. as Defender		Excluding Cases with Axis Aerial Sorties		Light & Heavy Tanks Treated Separately		
Km of Progress	74.22 (68.44)	30.29 (54.53)	47.54 (56.00)	37.98 (56.69)	77.26 (73.59)	42.12 (56.27)	73.31 (69.88)	-338.8 (361.6)	-492.9 (547.5)	-440.4 (379.5)	-807.6 (1,037)	-406.6 (417.1)	-1,591 (4,208)	-19.76 (116.1)
U.S. Fatalities	-0.386 (0.170)**	-0.015 (0.169)	-0.538 (0.196)**	-0.149 (0.205)	-0.744 (0.222)**	-0.189 (0.255)	-0.400 (0.183)**	-3.344 (2.904)	-2.117 (3.266)	-4.103 (3.783)	-5.477 (8.786)	-2.433 (2.078)	-8.367 (23.92)	-1.261 (0.670)*
Panel B: Mission Effectiveness Measured with Zero to One Index														
Index of Success	2,578 (753.8)**	3,101 (935.5)**	1,913 (790.6)**	3,093 (1,163)**	1,045 (673.4)**	2,506 (761.1)**	2,608 (769.5)**	3,064 (1,571)*	5,161 (1,511)**	3,029 (1,266)**	3,479 (1,068)**	3,756 (1,884)**	7,322 (3,132)**	3,197 (1,317)
U.S. Fatalities	-0.626 (0.202)**	-0.421 (0.270)	-0.717 (0.223)**	-0.616 (0.333)*	-0.842 (0.206)**	-0.615 (0.272)**	-0.618 (0.208)**	-1.227 (0.783)	-0.386 (0.926)	-0.664 (0.686)	-0.332 (1.063)	-0.838 (0.431)*	-0.270 (0.723)	-1.087 (0.640)*
Controls Include . . .														
Date & Continent	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Air & Enemy	Yes		Yes		Yes		Yes	Yes		Yes		Yes		Yes
Terr & Weath	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Human Fact	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Division Days	279	279	251	251	234	234	278	289	289	252	252	239	239	288
Engagements	152	152	140	140	131	131	151	162	162	141	141	136	136	161

Notes to Table A11: This table explores the sensitivity of the results by showing alternative specifications of the regressions in Table 2. Additional details in the text.

Table A12: Data Sources for U.S. Military Deaths in Division by Day Panel

Dataset	Sample	Variables	Source	Citation
Reading Room Data	Battle dead among those assigned to U.S. Army ground divisions. N=146,431	Name, serial number, division, battalion or regiment, rank, broad military occupational category, type of death, date of death for 41% of observations	Hard copy Xeroxed from Archives II reading room	U.S. War Department, 1947
U.S. Airborne Data	Battle and non-battle dead among those assigned to U.S. airborne divisions, attachments included. N=9,209	Name, division, battalion or regiment, company, rank, type of death, country of death, date of death, cemetery	Downloaded from website.	U.S. Airborne in WWII, 2010
Machine Records Data	Dead, wounded, captured, or missing, battle or non-battle, all U.S. military branches, 1941-1943, N=101,353	Name, serial number, home county, rank, broad category of military occupation, type of casualty, date of casualty	Hard copy Xeroxed from Archives II records	U.S. War Department, 1944
WWII Honor List	All battle and non-battle dead, all U.S. military branches, N=373,218	Name, serial number, rank, branch of service, type of death, hometown	FOIA request to ABMC	U.S. Navy, 1946; U.S. War Department, 1946
ABMC Cemetery Files	All battle and non-battle dead buried in U.S. military cemeteries, all U.S. military branches, N=180,735	Name, serial number, branch of service, divisional and battalion/regiment affiliation, rank, type of death, date of death, date of birth, age, home town, burial plot location, awards won	Purchased from ABMC	U.S. American Battle Monuments Commission, 2005
AGRS Remains not Recovered File	All dead and missing whose remains were not recovered by 1954, all U.S. military branches, N=79,021	Name, serial number, rank, branch of service, date of loss	FOIA request to DPMO	U.S. Army Graves Registration Service, 1954
WWII Serials File	Nearly all enlisted U.S. Army personnel who enrolled between 1938 and 1946, N=8,706,394	Name, serial number, home state and county, enlistment location, date of enlistment, rank, branch of service, term of enlistment, country of birth, year of birth, race and citizenship, education, civilian occupation, marital status, component of the Army	Purchased from NARA Electronic Records Division	U.S. National Archives and Records Administration, 2002
Adjutant General Final Report	U.S. Army battle casualties (incl. wounded and captured) and non-battle deaths N=936,259	Two-way tabulations include different types of casualties and deaths by division, by theater, and by month of occurrence	Hard copy Xeroxed from Archives II reading room	U.S. Army Adjutant General's Office, 1953.

Table A13: Estimated Costs for a 1942 Organic Infantry and Armored Division

	Infantry		Armored	
	Initial	Monthly	Initial	Monthly
(expressed in millions of 2009 dollars)				
Enlisted & Officer Pay	\$233.45	\$14.71	\$236.33	\$14.51
Enlisted & Officer Training	\$145.13	\$0.19	\$197.27	\$0.31
Major Divisional Equipment	\$119.80	\$4.30	\$1,114.84	\$71.00
Food	\$82.72	\$3.27	\$77.05	\$3.08
Clothing	\$58.02	\$2.77	\$54.35	\$2.14
Additional Equipment	\$36.40	\$3.55	\$34.17	\$3.92
Ammunition	\$19.65	\$7.98	\$22.40	\$19.24
Gasoline	\$2.97	\$1.25	\$4.29	\$3.85
Transportation	\$280.18	\$4.35	\$500.10	\$11.29
Total	\$978.34	\$42.36	\$2,240.78	\$129.35

Notes to Table A13: Compiled from various archival sources. Based on 1942 Tables of Organization and Equipment. In 1942, a standard infantry division included 15,514 troops and 0 tanks. In 1942, a standard armored division included 14,620 troops and 390 tanks. Transportation includes inter- and intra-continental transport costs for troops and equipment.