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Capital-labour substitution in defence provision

Ron Smith, Humm Anthony, Jacques Fontanel

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The choice between labour and capital arises for military expenditures necessary for national security. Economic constraints play a major role, because the military sector is highly technological and aims for the highest performance for its equipment, which has become very expensive. Should conscription be maintained? Is a highly capital-intensive defence function preferable? The countries that spend the most in military terms have higher per capita spending than other types of defence and the army is traditionally more "labour intensive".

Résumé : Le choix entre le travail et le capital se pose pour les dépenses militaires nécessaires à la sécurité nationale. Les contraintes économiques interviennent fortement, car le secteur militaire est hautement technologique et qu'il vise les plus hautes performances pour ses matériels devenus alors fort onéreux. Faut-il maintenir une conscription ? Peut-on préférer une fonction de défense fortement intensive en capital ? Les pays les plus dépensiers en termes militaires ont des dépenses par personne supérieures aux autres types de défense et l'armée de terre est traditionnellement plus « travail intensive ».

Dépenses militaires, structures des dépenses militaires, capital militaire, travail militaire, conscription.
Military expenditure, military expenditure structures, military capital, military labour, conscription.

Econometric studies of military expenditure have tended to emphasize either its economic consequence (for example, Chan 1985) or its determination (for example, Maizels and Nissanke in this volume). The military supply side by which factor inputs—such as armed forces weapon systems and logistic facilities—produce output has not been the subject of such econometric attention, though it is, of course, the focus of military science. This chapter presents some preliminary estimates of one aspect of the military supply side: the labour-intensity of defence provision.

Macro-statistical econometric procedures remain controversial in the analysis of military topics. Thus it seems useful to try to illuminate the advantages and limitations of these techniques, by also including a fuller discussion of the methodological issues involved in their application than is usual. This will be done in terms of the framework set out in Pesaran and Smith (1985). That paper proposed that econometric models should be evaluated in terms of three criteria: relevance to the required purpose, consistency within a theoretical framework, and adequacy at representing a particular sample of data.

The first section of this chapter discusses the purpose of the enquiry which is to obtain an estimate of the elasticity of substitution between military labour and capital, and explains why such an estimate is relevant to important military questions. To obtain an estimate of the elasticity of substitution requires an explicit model of the military production process: this is set out in the second section, which also discusses the role of formal models in ensuring the consistency of the analysis. The third section examines the statistical adequacy of the proposed model when it is estimated on data using both market exchange rates and Purchasing Power Parity (PPP) rates. The fourth section draws some general conclusions.

Purpose

The international analysis of military expenditure raises a range of questions in which knowledge of the extent to which military manpower is substituted for equipment plays an important role. For instance, in order to estimate Soviet military expenditure the CIA counts numbers of weapons and forces, then aggregates these components by valuing them at US prices and wages. The bias in this estimate will depend, in part, on the extent to which military technology allows substitution between personnel and equipment in response to different relative costs. It can be argued that the Soviets have larger armed forces, relative to the United States, because labour is a relatively cheap factor. In this case pricing Soviet forces at US wage rates is misleading. On the other hand, if the scope for substitution is small, the bias will be less, since the balance between personnel and equipment will be relatively insensitive to the difference in relative costs. Holzman (1980) discusses this index number problem in the measurement of Soviet military expenditure.

The extent to which substitution is possible can be measured by the elasticity of substitution—the percentage change in the personnel–equipment ratio in response to a percentage change in their relative cost. If the elasticity of substitution is zero—one pilot is required for each plane, for instance—changes in relative costs will have no effect on the labour intensity of defence provision. If the elasticity of substitution is unity, the share of personnel costs in total expenditure will remain constant, increases in factor cost being exactly balanced by reductions in factor use.

A second problem which involves some judgement about the extent of substitution arises in comparing defence budgets between countries with and without conscription. Given that the difference in wage rate between a conscript and volunteer is known there are two natural ways to correct the figures for the country with conscription. One is to assume that the size of forces would be constant, and calculate the budget which would result if volunteer rates were paid. The other is to assume that the personnel budget would be constant and calculate the size of forces that would result if volunteer rates were paid. Aben and Smith (1985, 1986) use both methods, conscript-corrected budgets and conscript-corrected forces, to compare British and French defence structures. The first method corresponds to assuming that the elasticity of substitution is zero,

the second method to assuming that it is unity. To provide a single estimate requires a value for the elasticity of substitution, which we might expect to lie somewhere between zero and unity.

The final problem involves the evaluation of the reliability of published numbers on military expenditure for Less Developed Countries (LDCs). A useful check is to see whether the implied proportion of the budget spent on personnel is reasonable. What is reasonable depends on the elasticity of substitution. If this is constant across countries, there should be a linear relationship between the logarithms of the share of personnel costs in the budget and the real wage, with a slope of one minus the elasticity of substitution. The very high shares of personnel costs in many LDCs, then suggest either that the elasticity of substitution is considerably greater than unity, that there are systematic shifts in the production function or that these countries are under-reporting their imported equipment purchases, as has been suspected. Deciding between these hypotheses requires estimates of the elasticity of substitution.

There are thus a range of important problems in the international analysis of military expenditure in which it would be useful to have an estimate of the elasticity of substitution between personnel and equipment, or military labour and capital, which could be used for comparisons between countries. The purpose of this chapter is to discuss estimates of the elasticity of substitution obtained from a cross-section of countries for which fairly good data are available. Were this to produce clear results, we might have some confidence in extrapolating to cases where the data are less good.

The model

Any process of estimation and testing requires the use of a theoretical model. In much applied work the model is implicit, taken for granted, and hardly even noticed. However, even the simplest regression requires choice of dependent and explanatory variables, specification of appropriate measures and functional form, and a set of stochastic assumptions that make a particular technique, such as Least Squares, an appropriate estimator. There are advantages, however, in using an explicit formal model. The assumptions are set out more fully, allowing them to be evaluated. The model suggests important variables, allows the interpretation of parameters, organizes the analysis and defines the limits of application. It is a deliberately simplified representation of reality designed to provide a framework

for thought, within which the data can be organized and questions of interest posed.

Implicit in the discussion of substitution between personnel and equipment is the notion of some underlying production function, which describes how the output of military services, denoted by M, is produced from factor inputs. We shall measure this output in the usual way by total expenditure. Military output is conceptually distinct from power or security, which are relative concepts. The inputs will be summarized as the services of military labour, S, measured by the number of armed service personnel, and the services of military capital, E, which is an aggregate of equipment, logistic infrastructure and civilian personnel. The Production Function will be represented in a Constant Elasticity of Substitution (CES) form:

$$M = \gamma \{(1-\delta)E^{-\varrho} + S^{-\varrho}\}^{-\nu/\varrho} \tag{1}$$

Optimization then requires that the authorities equate the marginal product of service personnel to the real military wage, W. Taking logarithms of the first order condition gives

$$\ln(M/S) = \sigma \ln W + \sigma\varrho\,((\nu-1)/\nu) \ln M + (\sigma\varrho/\nu) \ln \gamma - \sigma \ln \delta - \sigma \ln \nu \tag{2}$$

It was the constant returns to scale version of this equation that Arrow, Chenery, Minhas and Solow (1961) estimated from cross-country industry data. Derivations and discussion of estimation and inference for this model can be found in Wallis (1979).

The elasticity of substitution in this equation is given by $\sigma = 1/(1+\varrho)$. The other parameters also have meanings which provide a way to interpret the results. The returns to scale are given by ν, constant returns to scale implying $\nu = 1$. The labour intensity of the process as described by δ and γ is an efficiency parameter which describes the relation of output to weighted inputs.

It is clear that a model of this sort cannot be regarded as a literal representation of the true process. It provides what McCloskey (1983) calls a metaphor, a useful instrument for organizing thought and evidence; a window through which to view the data. The formal presentation also provokes a range of questions in a way that a vaguer formulation would not. For instance, making the assumptions about optimization, aggregation and common parameters explicit, immediately makes one examine their applicability.

If we look at the individual assumptions, it is immediately clear that aggregating all the other inputs but the armed forces into a single index E is not plausible. In particular the degree of substitution between military personnel and weapons, civilian personnel, and the other elements of E would differ. However, E does not appear directly in (2), the equation which will be used for estimation. Thus, choice of a measure for E does not play an operational role and the violation of the assumption may only have second order effects.

The assumption of optimization, which is used in the derivation, is very strong and it may be argued that the evidence of military inefficiency and the lack of incentives for the military to minimize cost suggests that it is inappropriate. In the absence of optimization, the estimated elasticity will reflect both technological substitution and behavioural substitution: the extent to which decision makers respond to relative prices and budget constraints. There will also be lags in response and slow adjustment, but these are likely to average out over an international cross-section.

The assumption of a common production function is less constraining than it appears, since we can relax it by allowing each of the parameters to be functions of other variables which might shift the production function. In particular, the production technology associated with land, air and sea forces is likely to differ, with land forces in general involving less equipment relative to the others. This lower capital intensity can be represented by making δ, which represents labour intensity, a function of A, the proportion of land forces in total personnel.

$$\delta = A^{\delta_1} \tag{3}$$

A number of experiments were carried out making γ a function of membership of alliances, possession of nuclear weapons, and other strategic factors, but none of these variables proved significant. Thus, for the moment, the efficiency parameter will be regarded as constant.

To move from the theoretical model to the estimated econometric model, we have to choose observable proxies for the variables. One particular difficulty is that suitable comparative cross-section data on military wage rates are not available. However, apart from conscription it might be expected that across countries the market wage will be proportional to per capita income, and that the military

wage would be depressed below this level by conscription. Therefore the military wage can be represented as

$$W = \beta Y R^{\alpha} \tag{4}$$

Y is GDP per capita, which is being used as a proxy for the relative cost of labour. R is the proportion of regular volunteer troops in the armed forces. Equations (2), (3) and (4) provide the basic elements of the model. If they are combined, the following estimating equation is obtained.

$$f = A0 + A1\,y + A2\,m + A3\,r + A4\,a + u \tag{5}$$

f is the productivity measure, the logarithm of military expenditure per member of the armed forces, $\ln(M/S)$;
y is the logarithm of per capita income;
r is the logarithm of the per centage of volunteers in the total armed forces;
a is the logarithm of the percentage of land forces in the total;
m is the logarithm of military expenditure;
u is a disturbance term, which is assumed to be independent normal with zero mean and constant variance.

The assumptions of normality and constant variance will be tested below.

The estimated coefficients are related to the structural parameters:

$$A0 = -\sigma \ln \nu + (\varrho\sigma/\nu) \ln \gamma + \sigma \ln \beta$$

$$A1 = \sigma$$

$$A2 = \varrho\sigma\,((\nu - 1)/\nu)$$

$$A3 = \sigma\alpha$$

$$A4 = -\sigma\delta_1$$

The parameters α, δ_1, ν and σ (ϱ) are just identified, in that we can solve for them uniquely from the estimated coefficients.

Equation (5) will treated as a 'reduced form' for the structural model described by equations (1) to (4). There are two aspects of this treatment that should be noted. Firstly, the right hand side regressors are regarded as exogenous, in that the disturbance is independent of them. However, since it is possible that M may be determined jointly with S, while R and A both are calculated from ratios to S, the exogeneity assumption may not hold. If other

variables known to be exogenous were available this assumption could be tested. As it is we have to rely on a theoretical derivation which suggests that countries determine their force structure in terms of proportions of volunteers and land forces and a level of military expenditure which can be regarded as predetermined. A possible process for the autonomous determination of military expenditure is described in Smith (1980).

The second aspect of the treatment of (5) as a reduced form for this structure arises because a similar equation, involving the same variables, might be generated by a quite different structural theory. Under our structure the coefficient of income measures the elasticity of substitution. Under an alternative structure, it might have a quite different interpretation. Alternative interpretations are discussed below. Another consequence of the possible consistency of this reduced form with other theories is that the adequacy of the estimated equation does not necessarily validate the structural model.

Estimates

The first set of estimates use data for M and Y in US dollars converted at market exchange rates. S is measured by full-time military personnel; allowing for reserves did not improve the explanation. Sample selection was largely determined by availability and reliability of data, omitting countries involved in costly wars or with a history of military involvement in domestic politics. The sample was: Australia, Austria, Belgium, Britain, Canada, Denmark, Eire, Finland, France, West Germany, Greece, Italy, Japan, Malaysia, Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Turkey, United States. The source of the data is IISS (1976–7).

The cross-section results for this sample of twenty-three countries for 1976 is given in column A of Table 3.1. The fit of the equation is reasonable for an international cross-section. The estimate of the elasticity of substitution at 0.6 is significantly different from zero and accords with our prior expectations. The hypothesis of constant returns to scale can be accepted, since the coefficient of m is not significantly different from zero. This also suggests that the endogeneity of m is not a problem. Military expenditure per member of the armed services is reduced both by a higher proportion of conscripts and of land forces. The hypothesis that the

Table 3.1 Regression results for three models

Dependent variable:	Model A m − s	Model B mp − s	Model C mp − s
y	0.604*		
	(0.099)		
yp		0.273	−0.192
		(0.154)	(0.285)
m	0.065		
	(0.044)		
mp		0.086	0.112*
		(0.038)	(0.041)
r	0.296*	0.296*	0.339*
	(0.132)	(0.117)	(0.112)
a	−0.780*	−0.928*	−1.002*
	(0.313)	(0.289)	(0.273)
d			−0.666
			(0.352)
int	−0.638	2.687	6.518*
	(2.209)	(2.473)	(3.073)
SER	0.272	0.244	0.288
J-B	1.439	4.470	9.0156*
$\bar{R}^2$	0.837	0.784	0.8118

Notes
n − 23, t − 1976.
Standard errors of coefficients in parentheses.
* indicates significantly different from zero at the 5% level.
SER is Standard Error of Regression.
J-B is the Jarque–Bera Asymptotic LM normality test, Chi Squared with 2 degrees of freedom.

residuals are normally distributed can be accepted, while other diagnostic tests did not indicate that the functional form was misspecified. The results do not seem sensitive to variations in the sample, and very similar estimates were obtained on a 1982 cross-section. Inspection of the residuals suggested that the presence of a

domestic arms industry might have a positive effect on military expenditure per member of the armed forces, but suitable data were not available to test this statistically.

Fuller details of the results obtained using income at market exchange rates, together with further discussion, can be found in Fontanel, Smith and Humm (1985). In general, our conclusion in this earlier paper was that the model appeared successful. It gives a well determined relationship between military expenditure per member of the armed forces and per capita income. The estimates imply a value of the elasticity of substitution and an effect of force structure which accords with prior expectations. The model passes a range of diagnostic tests, and appears to be stable over time. However, we noted that there have been a variety of criticisms of the use of per capita income at market exchange rates, and the sensitivity of the results to the measurement of income needed to be investigated.

The two main problems with per capita income data converted at market exchange rates are that they exhibit variance and bias. The large variance arises because market exchange rates fluctuate widely from year to year. If this is treated as a traditional measurement error problem, it would suggest that the income coefficient in column A would tend to be underestimated. The bias arises because market exchange rates deviate systematically from the real purchasing power of the currency, because of price differences between countries. In particular, low income low wage countries have lower prices than high income countries. As a result, market exchange rate estimates of GDP are biased downward. This problem can be dealt with by valuing the quantities of goods and services produced in each country at common 'international' prices to give real or PPP estimates of national product. Kravis (1984) and Marris (1984) provide a survey and discussion of the issues involved in this calculation.

In terms of the theoretical model introduced above, it is not clear that PPP income is the more appropriate variable. Income is acting as a proxy for relative labour costs and by valuing output at international prices, the PPP income measure strips out a lot of the variation in labour costs across countries. The bias in market exchange rate income as a measure of real product arises partly because non-traded goods, such as services, tend to be relatively labour intensive and thus relatively cheaper in poor countries. The PPP measure removes this effect. Since the PPP measure is a poorer

proxy for the theoretical variable we might expect it to have a lower coefficient.

Estimates of real GDP per capita, adjusted for the terms of trade, measured in 1975 international dollars were taken from Summers and Heston (1984), the series they call RGDP. Call this PPP estimate of real per capita income YP and the market exchange rate estimate Y. The ratio $D = YP/Y$ measures the exchange deviation, the divergence between the market and PPP exchange rate. This ratio takes the value unity for the US and greater than unity for other countries, the deviation being larger for lower income countries. An estimate for real military expenditure can then be obtained by multiplying nominal military expenditure by the exchange deviation, that is $MP = D\,M$. It should be noted that this procedure only corrects for the overall deviation between market and PPP rates. It does not allow for the fact that the relative price of M to Y differs between countries.

Using lower case letters for logarithms, the model is then:

$$mp - f = B0 + B1\,yp + B2\,mp + B3\,r + B4\,a \qquad (6)$$

The results are shown in the second column of Table 3.1. The use of PPP rather than market exchange rate figures has led to a reduction in the standard error of the regression, though the R squared is also smaller, since the variance of mp is considerably less than the variance of m. The main feature of the results is that the coefficient of income is now much smaller, and the estimated elasticity of substitution is not significantly different from zero.

The models in columns A and B are not nested, and so cannot be directly tested against each other. However, noting that $mp = m + d$ and $yp = y + d$ they can both be nested within a model of the form:

$$(m+d) - f = C0 + C1(y+d) + C2(m+d) + C3r + C4a + C5d \qquad (7)$$

The results for this are given in column C of Table 3.1. The restriction $C5 = 0$ has a t statistic of -1.89, so we can just accept model B against model C at the 5 per cent level. Model A can be obtained from model C, by the restriction $C5 = 1 - C1 - C2$. The t statistic for this restriction is 2.92 which rejects model A against model C. Model C is an artificial model merely designed to nest models A and B. It has no obvious theoretical basis or interpretation given the negative coefficient on income. It is possible that the exchange deviation variable d, which has a negative sign, may be

acting as a proxy for relative labour costs. Low labour cost countries tend to have a large exchange deviation and lower military expenditure per member of the armed forces.

These results are rather unsatisfactory. Model A, using market exchange rates, has coefficients that accord with prior expectations, but is rejected by the data. Model B, using PPPs, is not rejected by the data but implies an implausibly low estimate of the elasticity of substitution. Of course, one might expect the PPP estimate to be low if one accepts the argument that it is a worse proxy for the relevant variable, relative labour costs. However, if it is a worse proxy it should also fit less well, whereas in fact it fits better.

These results might lead us to reconsider the specification. One possibility, within the framework that we have been using is that the efficiency of military production is related to the general level of productivity in the society. This would suggest that the efficiency parameter is a function of per capita income. Suppose it is assumed that:

$$\gamma = \gamma_\phi Y^{\gamma_1} \tag{8}$$

The coefficient of per capita income, which up to now has been interpreted as the elasticity of substitution, is then given by $\sigma + \gamma_1$ $(\rho\sigma/\nu)$, which is a mixture of both substitution and technical change effects.

The effect of this can be seen if we write the first order condition for the CES production function in the form:

$$\ln (WS/M) = A + (1-\sigma) \ln W + (\sigma - 1) \ln \gamma \tag{9}$$

If we assume that the elasticity of substitution lies between zero and unity, this equation says that the share of personnel costs in military expenditure is a positive function of the wage, and a negative function of the efficiency parameter. The relationship between the share of personnel costs and per capita income, then depends on how wages and efficiency change with income.

Conclusion

The econometric approach adopted in this paper was justified by three arguments. These are that estimates of the elasticity of substitution between military labour and capital are relevant to a number of interesting military questions; that formal theoretical models enable us to analyse the available data within a consistent

framework; and that statistical techniques allow us to evaluate the adequacy with which the proposed model represents the data. It is not claimed that the procedure guarantees satisfactory results or necessarily produces unambiguous answers, and it has not done so in this case.

The results discussed above would not lead one to revise a prior belief that the elasticity of substitution between military labour and capital probably lay between zero and one. However, the results do suggest that the specification of the model is unsatisfactory in a number of ways. The most effective way of improving the specification would be to evaluate and extend the model using more informative data which could distinguish between competing interpretations of the results. The estimates obtained from the data available on this single cross-section do not allow us to decide whether the variance introduced by fluctuations in market exchange rates contaminates the results, whether market rate or PPP measures of national income are better proxies for labour costs, or whether there are income-related shifts in efficiency.

There are a number of obvious ways to extend the data. Rather than use a single cross-section, time-series for a sample of countries could be pooled. Measures of military capital could be constructed from the available data on holdings of different types of equipment and used to test the concept of an underlying production function. The relative prices for disaggregated components of GNP could be used to examine substitution responses directly. These are all possibilities for future research within an econometric framework.

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