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EXCESS CAPACITY IN WEAPONS PRODUCTION: AN EMPIRICAL ANALYSIS*†

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This paper analyzes a set of observations by the Congressional Budget Office (CBO) on individual weapons systems regarding whether large amounts of excess capacity exist and whether short run average cost (SRAC) appears to be severely decreasing. It is shown that the amount of excess capacity and steepness of SRAC are essentially independent of output rate. It is then argued that this suggests that production is occurring in inefficiently large plants—i.e.—off the long run cost curve.

KEY WORDS: Excess capacity, stretchouts.

1. INTRODUCTION

A well-accepted fact concerning military procurement is that major weapons sytems are typically produced at much lower rates than those that were projected prior to the start of production. Two Rand researchers have summed up the situation as follows.

> The full-planned production rate (for which the production line was designed to be efficient) is seldom achieved or, if achieved, rarely long maintained ... (some aircraft, for example , have been produced at rates of less than one or two per month).... No major Air Force program has been procured to the original plan since 1969, and the other services display no greater stability. (Dews and Birkler, 1983, p. 3.)

See Air Force Systems Command (1983, pp. E56–E57), Congressional Budget Office (1987a, p. 29), and Gansler (1989, chapter 5), for similar conclusions.

This raises the question of whether production is occurring in plants of efficient scale or not. If one believes that production lines are constructed to efficiently produce the formally projected levels of output, then this implies that existing plants are of too large a scale given actual output levels. However, military planners should be able to privately formulate unbiased predictions of future output rates regardless of formal projections. If they choose production lines to be efficient given their unbiased predictions of future output rates, then this implies that existing plants should on average be of the correct scale given actual output levels.

Either belief is *a priori* plausible. Traditional policy analysts have generally tended

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to (implicitly) adopt the former belief and conclude that over-projections cause inefficiently large levels of capacity.[1] Economic theorists are of course much more tightly wed to the "rational actor" paradigm and thus might be initially more inclined to opt for the latter belief. However, the requirement that actors be rational does not actually require one to adopt the second belief. In another paper (Rogerson, 1990), I have argued that rational military planners might purposely choose the scale of production lines to be inefficiently large as a strategic device for manipulating Congress's budget decisions. The argument in Rogerson (1990) can be briefly summarized as follows. Because of the military's technical expertise, Congress delegates the design choice of production facilities to the military. However, Congress retains the final authority to decide how many (if any) units of the weapon to buy. Thus one can model this as a two stage game where the military chooses scale at stage one and then Congress chooses how many units (if any) to buy at stage two. The military's goal is to maximize the number of units produced. The key idea is that by increasing capacity, the military lowers marginal cost and thus increases the amount that Congress will buy (so long as it buys any). Thus the military will expand capacity until production is so inefficient that Congress is indifferent between buying and not buying the system. This maximizes the number of units purchased. In Rogerson (1990) it is formally proven that the scale of production is too large in the resulting equilibrium. That is, the equilibrium output could be produced more cheaply in a plant of a smaller scale. Thus inefficient production is essentially an unintended by-product of the military's attempts to expropriate the social surplus arising from weapons programs by inducing Congress to increase the quantities purchased.

In summary, the question of whether defence production occurs in plants which are of systematically too large a scale or not is an empirical question whose answer is not *a priori* obvious. It is of course of direct importance insofar as production costs are higher than necessary if scale choices are inefficient. However, it is also of interest because of its implications for how we model and think about the decision-making process within the defence bureaucracy. In particular, if we insist on rational actors, then the existence of inefficient scales implies that some sort of strategic interaction between or within Congress and the military must be producing this outcome.

Unfortunately there is very little publicly available evidence regarding this issue. The problem is that investigating the question of efficient scale really requires one to calculate long run cost curves—i.e.—to calculate how costs vary as the nature of the production facility is changed. However, it is generally much easier to investigate the nature of the short run cost curve given the production facility that is in place. All the publicly available studies that I am aware of which attempt to show that production rates are inefficiently low in fact only consider data on short run cost curves.[2] They attempt to establish two properties:

Property #1: Steeply Declining SRAC
The short run average cost (SRAC) curve is steeply declining at current output rates.

Property #2: High Excess Capacity
Current output rates are far below the maximum possible output of existing facilities.

1. See Air Force Systems Command (1983), Congressional Budget Office (1987a, b), Dews and Birkler (1983), and Gansler (1989).

2. See the previously cited studies in note 1.

Of course neither of these properties necessarily establishes that production is occurring off the long run cost curve.[3]

The purpose of this paper is to show that a logically correct method does exist for using the existing data to make inferences regarding whether production is efficient or not. The method is based on making the assumption that relatively similar types of weapons have the same long run cost curve. Given this maintained assumption, suppose we wish to test the null hypothesis that production of a group of weapons systems is occurring efficiently—i.e.—on the long run cost curve. Then under the null hypothesis, a set of data describing properites of the short run cost curves for a cross-section of similar systems being produced at different rates also provides information about the long run cost curve. One can therefore test the null hypothesis by seeing whether the implied properties of the long run cost curve are reasonable or not.

More specifically, it will be argued that under the null hypothesis, it is reasonable to expect that both Property #1 and Property #2 are less likely to be true for weapons systems being produced at higher rates. This means that one can indirectly test for productive efficiency by testing whether Property #1 and Property #2 become less true for systems being produced at higher output rates.

The best and most comprehensive data investigating Properties #1 and #2 for a cross-section of weapons systems is contained in a report by the Congressional Budget Office (CBO) (1987b).[4] This paper will perform a simple econometric analysis of the CBO data and show that Property #1 and Property #2 appear to be totally unrelated to current output rates. That is, knowing the output rate of a system would be of no value if one were trying to guess whether the CBO concluded that the system had steeply declining SRAC or large amounts of excess capacity. Given the theory of this paper, this suggests that production is not occurring on the long run cost curve.

One final comment regarding the interpretation of this paper's results should be noted. One can view this paper as establishing two conclusions. The first conclusion is empirical. This is that the CBO's determination of whether a system exhibited steeply declining SRAC or large amounts of excess capacity is entirely unrelated to production rate. The second conclusion is theoretical. This is that the first conclusion suggests that production is not occurring on the long run cost curve.

The empirical conclusion is clearly and unambiguously correct. However, the theoretical conclusion is more tenuous. On an intuitive level it is quite appealing. The CBO essentially can be viewed as identifying systems where costs are "too high". If the systems with costs that are too high also tend to be the systems produced at the lowest rates it would be reasonable to interpret the CBO as simply observing the fact that LRAC declines with production rate. However, if there is no such correlation, then it is reasonable to interpret the CBO as claiming that production is not occurring efficiently.

The second, theoretical, conclusion of this paper is simply a formalization of this intuition. However, the formalization makes it clear that a number of strong assumptions must be made to rigorously justify this interpretation. The essential

3. This will be discussed further in Section 2.

4. Recently Lichtenberg (1989) has shown that publicly available DoD data from Selected Acquisition Reports can be used to directly estimate the short run cost elasticity for various weapons systems. Lichtenberg's methodology could provide an alternate source of data for the calculations of this paper. This is an interestng subject for future research.

problem is that conclusions regarding long run cost are difficult to make if one only has qualitative data on short run cost. Therefore readers skeptical of some of the required assumptions might interpret the contribution of this paper's second conclusion as being that it explicitly recasts the production rates debate in an economic framework and shows that existing empirical studies do not allow strong conclusions regarding the most important questions. Of course, readers less skeptical of the required assumptions will also be able to view this paper as providing at least some evidence that the CBO (1987b) should be interpreted as identifying weapons systems being produced in plants of inefficiently large scale given existing production rates.

The paper is organized as follows. Section 2 describes the theory underlying the proposed test in more detail. Then Section 3 presents the empirical analysis of the CBO data. Finally Section 4 offers some concluding remarks.

2. THEORY

Figure 1 illustrates the stylized situation being considered. The long run average cost curve, labeled LRAC, is drawn to be declining everywhere since this is probably the case over all relevant ranges of production for most weapons systems. Each possible production facility has a short run average cost (SRAC) curve tangent to LRAC at one point. Larger scale production facilities are tangent to LRAC further to the right. The short run average cost curves for two production facilities are drawn in the figure. These are denoted by $SRAC_1$ and $SRAC_2$. Suppose that x^* is the current level of production. Then the cost minimizing technology is technology 1. This would

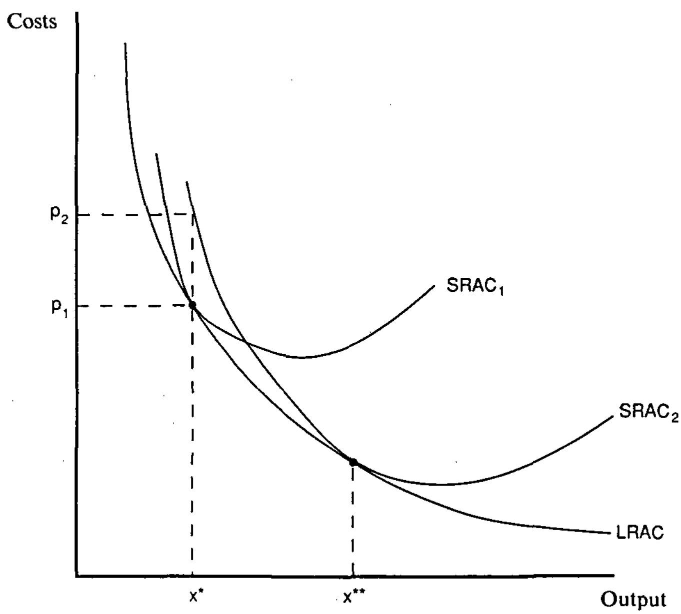

Figure 1 Short run and long run average cost curves

yield average costs of p_1. If a larger scale technology were used average costs would be higher. For example if technology 2 were used then average costs would be p_2.

This standard neoclassical graph will turn out to be a useful method for demonstrating the desired results regarding Property #1, the slope of SRAC. However it will not be particularly useful for demonstrating the desired results regarding Property #2, excess capacity. Instead, a simple algebraic example where excess capacity is the result of indivisible inputs will be used to develop the desired results regarding Property #2. Thus essentially two different models will be used to develop the two desired results. Of course one could "unify" the two models in a more complex single model of a neoclassical cost function with an indivisible input. However no extra insight is gained by doing so.

The first point to establish is that if Property #1 and/or Property #2 hold true for a given weapons system, this does not necessarily imply that production is occurring off the long run cost curve. That is, both properties are actually consistent with operation on the long run cost curve. First consider Property #1, declining SRAC. So long as LRAC is declining then so will SRAC, even when scale choice is efficient. This is illustrated in Figure 1. Observe that SRAC_1 is declining at x^*. In order to interpret Property #1 as supporting the existence of excessive scale one must therefore draw a subjective and judgmental conclusion. Namely, one must conclude that short run average cost is declining *so* dramatically that it seems very implausible that the existing technology is the cheapest method producing the existing output.

Now consider Property #2, excess capacity. Once again, it is not directly obvious how this relates to the issue of excessive scale. In particular, one would expect that even an efficiently sized plant would not be run at 100 percent of maximum capacity. Thus one must somehow know the optimal utilization rate in order to use existing utilization rates to infer the existence of productive inefficiency. The CBO (1987b), for example, essentially simply states that in its judgment the existing utilization rates averaging 43 percent of maximum capacity are too low to possibly be optimal. The only evidence cited is that commercial manufacturing typically exhibits much higher utilization rates of perhaps 70 percent (CBO, 1987b, p. 12). Although their conclusion seems plausible, it is not supported by objective analysis of cost functions. In particular, as for Property #1, it may be possible that the observed objective evidence is consistent with operation on the long run cost curve. One compelling explanation, for example, is that there are large indivisibilities in defense production. Thus it may be efficient to construct a plant capable of producing perhaps 150 aircraft per year even if only 20 aircraft per year will be produced.

Now the theoretical basis for the empirical methodology to be employed by this paper will be explained. Suppose that we are considering a cross-section of weapons systems with the same long run average cost curve. However, different systems are being produced at different rates. Now consider the null hypothesis that all the systems are being produced efficiently—i.e.—on the long run cost curve. It will now be argued that we would expect both Property #1 and Property #2 to become less true for systems being produced at higher rates.

First consider Property #1. So long at LRAC is convex, we would expect the slope of SRAC to be flatter for aircraft being produced at larger levels of output. For example, in Figure 1, if x^* and x^{**} are both being produced efficiently then the slop of SRAC is flatter for x^{**} than x^*. Therefore we would expect Property #1 to be less true for aircraft being produced at higher outputs. Now consider Property #2.

Suppose that the existence of large amounts of excess capacity is explained by indivisibilities. Then once again, we would expect excess capacity to become less evident for aircraft being produced at larger output levels. For example suppose capacity can only be added in discrete "lumps" of x units. Let y denote the desired production rate. Then a facility employing n lumps of capacity will be used to produce rates in the interval:

$$(n-1)x < y \leqslant nx \tag{1}$$

The largest amount of excess capacity will occur as y approaches the lower bound, $(n-1)x$. Therefore if a facility employing n lumps of capacity is observed, its maximum value for the quantity "observed excess capacity as a fraction of total capacity" will be x/nx which equals $1/n$.[5] This obviously decreases in n. The general point this illustrates is that the effects of lumpy investment *measured as a fraction of total investment* ought to decrease as total investment increases.

Before proceeding with the empirical analysis two final remarks should be noted about this methodology. First, the requirement that an entire group of weapons systems have the "same" long run cost curve is not really as stringent as it would appear. It is not required that the long-run cost curves be the same in all respects. For the methodology to be valid when applied to Property #1, it must be the case that significant long-run economies of scale occur over the same ranges of output for all systems. For the methodology to be valid when applied to Property #2, it must be the case that the nature of indivisibilities is the same across all systems. To further deal with this potential problem, the analysis of the next section will only consider weapons systems that are aircraft or missiles. Furthermore, all regression results will be reported for the case where the aircraft and missiles are treated as two separate groups as well as for the case where they are treated as a single pooled group. The requirement that production of all aircraft or all missiles exhibit relatively similar long-run economies of scale and indivisibilities of capacity seems fairly reasonable.

The second remark regards the issue of surge capacity. Because of the need for extra production capability in the event of war, it may be the case that it is optimal to purposefully choose the scale of production lines to be larger than that which would efficiently produce the peacetime rate. If this is true, then the null hypothesis that "scale choice minimizes the cost of producing the observed peacetime rate" is not quite correct. It should be replaced by the revised null hypothesis that "scale choice minimizes the expected cost of production taking into account the peacetime rate, the probable war-time rate, and the probability of war."

In particular this means that we must then show that under the revised null hypothesis it is reasonable to believe that Property #1 and Property #2 become less true for systems with larger peacetime rates. There are two responses to this issue.

The first response is that it is not at all clear that the need for surge capacity plays a significant role in the production plans for major weapons systems. This is because, even with a physical plant in place, the production of major weapons systems is a very slow process, perhaps requiring two to three years. Thus most wars would be long-finished before surge capacity for major weapons systems could be brought into play. Thus while surge capacity may be an important consideration for munitions

5. Recall that this is under the null hypothesis that production is efficient—i.e.—in the context of this example, no more machines than necessary are purchased.

and other sorts of quickly producible items, it may not be an important concern for major weapons systems.[6] Gansler (1980, p. 177) for example, concludes that "under current planning and mobilization policies it would take about two years before any increased outputs would be realized from existing in-use production lines, and three years before any significant effect on force structure would be felt.... Thus, for a 'short war' scenario, the existence of substantial excess production capacity has limited value."

The second response to the surge capacity issue is that so long as the need for surge capacity affects all systems equally, then it is still reasonable to conclude that Property #1 and Property #2 exhibit the desired behavior. This is particularly true for Property #2, excess capacity, so it will be considered first. As before, assume that capacity can be added only in lumps of x units and let y denote the peacetime rate. However now assume that military planners require capacity to exist sufficient to produce $(1+\lambda)$ times the peacetime rate where $\lambda > 0$. Then n lumps of capacity will be used to produce peacetime rates in the interval determined by:

$$(n-1)x < (1+\lambda)y \leqslant nx \tag{2}$$

The maximum amount of excess capacity will occur as y approaches the lower bound of this interval. Therefore if a facility employing n lumps of capital is observed, its maximum value for the quantity "observed excess capacity during peacetime as a fraction of total capacity" will be:

(3) which can be rewritten as:

$$\frac{nx - \dfrac{(n-1)x}{1+\lambda}}{nx}$$

$$1 - \frac{n-1}{n(1+\lambda)} \tag{4}$$

This decreases in n. Therefore, the effects of indivisibilities *measured as a fraction of total investment* will still grow smaller as total investment increases.

It is more difficult to develop an extremely general formal argument that we should still expect the slope of SRAC to decrease. The basic situation is illustrated in Figure 2. Two different peacetime rates x_1 and x_2 are produced using production lines with short run average cost curves SRAC_1 and SRAC_2. Because of the need for surge capacity both peacetime output rates are produced in plants of scales somewhat larger than the efficient scale. Thus the tangency of SRAC_i with LRAC, denoted by x_i^*, occurs to the right of x_i. Convexity of the LRAC curves implies that SRAC_1 is steeper than SRAC_2 measured at the tangency with LRAC. In the figure this means that the slope of SRAC_1 at x_1^* is steeper than the slope of SRAC_2 at x_2^*. However, what we need to show is that SRAC_1 is steeper than SRAC_2 at the rates actually chosen—i.e.—that the slope of SRAC_1 at x_1 is steeper than the slope of SRAC_2 at x_2. It seems likely that if the need for surge capacity is similar for both systems, then x_i/x_i^* will be relatively similar for both systems. Then so long as the shapes of two short run average cost curves are similar, the desired property will hold. Thus in

6. Note that this means that surge capacity may be a more important factor for missiles than for aircraft. This suggests another reason for separately analyzing the aircraft and missile data.

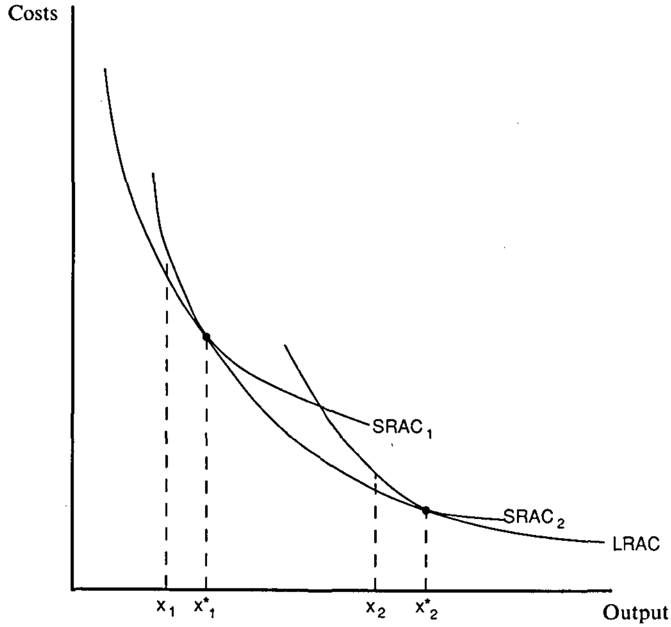

Figure 2 The effects of surge capacity

"well-behaved" examples we might still expect Property #2 to exhibit the desired behavior, but this argument is clearly not as strong as that for Property #1.

In summary, it is not clear that the need for surge capacity plays a significant role in procurement plans for major weapons systems. Even if it does, the methodology of this paper is still correct (particularly when applied to Property #2) so long as the need for surge capacity is similar for all systems.

There may also be other reasons why the DoD purposely chooses capacity in excess of that which would be required to produce the expected peacetime rate. For example, the DoD may went to encourage rivalry among weapons producers. The same comment applies to all of these reasons. The approach of this paper is still correct so long as the need for excess capacity is the same across all systems.

3. EMPIRICAL ANALYSIS

The basic conclusion of Section 2 is that if production is occurring on the LRAC curve, then both Properties #1 and #2 will tend to diminish for systems produced at higher outputs. In particular, suppose that the production rate does not appear to be correlated with either excess capacity or slope of SRAC over a cross-section of similar programs. Then this would provide some evidence that production is not occurring on the long run cost curve. This will now be demonstrated using a data set gathered by the CBO (1987b). As stated in Section 2, attention will be restricted to aircraft[7] and missiles and each of these two groups will be analyzed separately in order to help control for potential differences in technologies.

7. The term "aircraft" will be used to refer to fixed-wing aircraft and helicopters.

Table 1 Production rates for aircraft[a]

System	*Annual rate (R)*	*Minimum economic rate*	*Maximum rate*	U^b_{MIN}	U^b_{MAX}	U^b_{BIN}
E-2C Hawkeye Aircraft	7	6	18	117%	39%	100
SH-2F Seasprite Helicopter	8	6	48	133%	17%	100
A-6E Aircraft	8	12	72	67%	11%	0
C-2 Greyhound Aircraft	8	8	9	100%	89%	100
P-3C Aircraft	8	16	24	50%	33%	0
EA-6B Prowler Aircraft	9	6	24	150%	38%	100
KC-10 Tanker/Cargo Aircraft	9	8	24	113%	38%	100
CH-53 Super Stallion Helicopter	12	12	24	100%	50%	100
C-5B Transport	15	4	24	375%	63%	100
EH-60 Quickfix Helicopter	17	24	48	71%	35%	0
F-14A Aircraft	21	12	96	175%	22%	100
SH-60B LAMPS Helicopter	23	24	60	96%	38%	0
B-1B Bomber	31	24	48	129%	65%	100
AV-8B Aircraft	34	36	72	94%	47%	0
F-15 Aircraft	41	120	144	34%	28%	0
F/A-18 Aircraft	84	84	145	100%	58%	100
UH-60 Black Hawk Helicopter	85	96	144	89%	59%	0
AH-64 Apache Helicopter	117	72	144	163%	81%	100
F-16 Aircraft	155	108	324	144%	48%	100
Aircraft Average	36	36	79	100%	46%	63

[a] This is from CBO (1987b), pp. 10–11. Annual rates are averages for 1983–87.

[b] $U_{MIN} = \frac{\text{Annual rate}}{\text{Min. econ. rate}} \times 100\%$

$U_{MAX} = \frac{\text{Annual rate}}{\text{Max. rate}} \times 100\%$

$U_{BIN} = \begin{cases} 100, & U_{MIN} \geqslant 1 \\ 0, & U_{MIN} < 1 \end{cases}$

The CBO data set contains 40 major weapons sytems. However, three of the 40 systems analyzed by the CBO were neither a missile nor an aircraft so were discarded Two other systems were discarded because they had not yet entered full-rate production.[8] This left 35 weapons systems, 19 aircraft and 16 missiles.

Tables 1 and 2 present the CBO data for, respectively, the aircraft group and the missile group. Table 2 also presents the averages for each group and the average across both groups. The first column is simply the average annual production rate in number of units over the 1983–87 time period. It will be donated by R. The second column is what the CBO terms the "minimum economic rate". This is defined as "the point on the cost schedule below which unit costs rise at an excessive rate" (CBO, 1987b, p. 9) and is simply a number reported by program managers for each system. No systematic or uniform method for determining this rate exists and the rate is thus a highly suspect number as the CBO (1987b, p. 12) itself admits. It seems possible, for example, that program managers might have a variety of incentives to purposefully misreport this number. Nonetheless, it is the only available measure for all 35 systems

8. The three systems discarded because they were neither an aircraft nor missile, were the M1 tank, the Bradley Fighting Vehicle, and the multiple launch rocket system. The two systems discarded because they had not yet entered full-rate production were the Tomahawk and AMRAAM missiles.

Table 2 Production rates for missiles[a]

System	*Annual rate (R)*	*Minimum economic rate*	*Maximum rate*	U^b_{MIN}	U^b_{MAX}	U^b_{BIN}
MX	17	21	48	81%	35%	0
Ground Launched Cruise Missile	99	120	600	83%	17%	0
Tomahawk	186	300	540	62%	34%	0
Phoenix	222	240	420	93%	53%	0
Harpoon	284	360	660	79%	43%	0
Standard Missile 2 (extended range)	296	360	480	82%	62%	0
Patriot	485	240	840	202%	58%	100
Standard Missile 2 (medium range)	552	480	844	115%	65%	100
Laser Maverick	1 300	1 800	3 600	72%	36%	0
HARM	1 460	3 240	6 480	45%	23%	0
Sparrow	2 015	1 200	3 804	168%	53%	100
Sidewinder	2 122	2 400	8 400	88%	25%	0
IIR Maverick	2 205	6 000	10 800	37%	20%	0
Stinger	3 359	1 800	11 520	197%	31%	100
Hellfire	6 131	1 500	6 720	409%	91%	100
TOW 2	15 482	21 600	30 000	72%	52%	0
Aircraft average	36	36	79	100%	46%	63
Missile average	2 275	2 604	5 360	87%	42%	31
Aircraft and Missile average	1 060	1 210	2 493	88%	43%	49

[a] This is from CBO (1987b), pp. 10–11. Annual rates are averages for 1983–87.

[b] $U_{\mathrm{MIN}} = \dfrac{\text{Annual rate}}{\text{Min. econ. rate}} \times 100\%$

$U_{\mathrm{MAX}} = \dfrac{\text{Annual rate}}{\text{Max. rate}} \times 100\%$

$U_{\mathrm{MIN}} = \begin{cases} 100, & UB_{\mathrm{MIN}} \geqslant 1 \\ 0, & U_{\mathrm{MIN}} < 1 \end{cases}$

of how steep the short run average cost curve is at the current output level. Thus it will be used. The third column presents the maximum output rate for each system given the current production facility. This number is once again derived from DoD reports but it is more reliable since a more precise definition of it exists. The fourth and fifth columns present the current output rate as a percentage of the minimum and maximum output rates. These will be called, respectively, the minimum utilization rate and the maximum utilization rate and will be denoted, respectively, by U_{MIN} and U_{MAX}. Finally the sixth column is a binary variable which records whether the current rate is greater or less than the minimum economic rate. This is denoted by U_{BIN} and will be called the binary utilization rate:

$$U_{\mathrm{BIN}} = \begin{cases} 100, & U_{\mathrm{MIN}} \geqslant 100 \\ 0, & U_{\mathrm{MIN}} < 100 \end{cases} \tag{5}$$

It is straightforward to test whether Property #2 holds constant over various production rates. This is because U_{MAX} is an inverse measure of excess capacity. The test of whether Property #1 holds constant over various production rates is less direct and probably therefore less reliable. The minimum economic rate is defined to be a point where the slope of SRAC becomes quite steep. Therefore U_{MIN} can perhaps be interpreted as an inverse measure of the slope of SRAC. One might feel that U_{MIN} is transmittng more information than is available regarding relative slopes. That is, one might interpret the CBO data as simply reporting a binary variable. This is whether the slope is "high" (i.e.—$U_{MIN} < 100$) or "low" (i.e.—$U_{MIN} \geqslant 100$). Therefore an alternate inverse measure of slope is U_{BIN}.

Therefore we would expect all three utilization rates to fall as the production rate increases if production occurs on the long run cost curve. As a formal statistical matter we are testing the hypothesis:

$$H_0\colon U_x \text{ is constant over output rates}$$

against the alternative:

$$H_1\colon U_x \text{ falls as output rates rise}$$

where $x \in \{\text{MIN, MAX, BIN}\}$.

Table 3 reports the results of running the linear regression:

$$U_x = \alpha + \beta R \tag{6}$$

Results for $x \in \{\text{MIN, MAX, BIN}\}$ are reported. As well, for each x, the results of three separate regressions for aircraft, missiles, and aircraft and missiles combined are reported. Thus there are nine regressions. The first five columns are self explanatory. The sixth column labeled "t_β" is the t-statistic for β. The seventh column labeled $\bar{U}_x$ is the average value of U_x. The final column is the percentage of the average explained by the intercept term.

An appendix to this paper reports the results of estimating a variety of alternative specifications for the regression equation. It is shown that the qualitative conclusions

Table 3 Regression results

Regression x	*Group*	α	β	R^2	t_β[a]	$\bar{U}_x$	$(\alpha/\bar{U}_x) \times 100\%$
MAX	Aircraft	38.6	0.1809	0.14	1.68	45.2	85%
	Missiles	40.8	0.0013	0.06	0.95	43.6	94%
	Both	43.5	0.0010	0.02	0.79	44.5	98%
MIN	Aircraft	118.7	0.0636	0.00	0.16	121.0	98%
	Missiles	107.2	0.0047	0.04	0.75	118.8	90%
	Both	115.7	0.0037	0.02	0.74	119.5	97%
BIN	Aircraft	58.8	0.1192	0.01	0.42	63.2	93%
	Missiles	29.9	0.0006	0.00	0.18	31.3	96%
	Both	50.5	−0.0018	0.01	−0.57	48.6	104%

[a] Significance levels are as follows for the regressions:

	$t_{0.05}$	$t_{0.10}$	$t_{0.25}$
Aircraft	1.74	1.33	0.69
Missiles	1.76	1.35	0.69
Both	1.65	1.28	0.67

which will be described below are robust to a variety of alternate specifications. Some of these alternative specifications are more theoretically desirable because they are designed to deal with the fact that U_x is generally either a limited dependent variable or a binary qualitative choice variable. However, since none of the qualitative conclusions are altered and the specification in (6) is the simplest, the results for this specification will be reported and discussed in the main body of the paper. Readers interested in the results from alternative specifications should refer to the appendix.

The results generally support the conclusion that production rates have no significant effect on utilization rates. This is for two reasons. First, the values of β are not significantly different from 0 for any of the regressions. One cannot reject the null hypothesis that $\beta = 0$ with 95 percent confidence for any of the regressions. The regression using U_{MAX} for aircraft has β significant at a 90 percent level. However all the other regressions yield insignificant β's at the 90 percent level as well. Second, the magnitudes of the estimated β's are very small. Thus production rate differentials have a very small impact on utilization rates even if they are viewed as statistically significant. This can be illustrated as follows. For any given regression let $\bar{R}$ and $\bar{U}_x$ denote the mean of R and U_x. Then, according to the regression equation, a program with extremely low output will exhibit a utilization rate equal to $(\alpha/\alpha + \beta\bar{R}) \times 100\%$ of the average program. This equals $(\alpha/\bar{U}_x) \times 100\%$ because the regression line goes through the means. These figures are reported in the last column of Table 3. The lowest percentage is 85 percent and all others are over 90 percent, with many over 95 percent. Thus as the production rate increases from 0 to the average rate there is only a small percentage impact on the utilization rate, according to the regression results.

A number of other remarks should be noted about these regressions. First, the U_{BIN} variable appears to have the least positive correlation with R of the three utilization variables. The values of β are not significantly different from 0 at even the 75 percent level for all of these regressions. Thus the probability of production occurring below the minimum economic rate appears to be totally unrelated to the level of production.

Second, the values of β for the missile regressions are always less than the corresponding values of β for the aircraft regressions. Thus the evidence that missile production occurs off the long run cost curve is greater. This is consistent with other aspects of the data. Namely, with reference to the bottom rows of Table 2, missile production appears to be less efficient than aircraft production by almost any measure. The average aircraft program operates at 100 percent (46 percent) of its minimum economic (maximum) rate while the average missile program operates at only 87 percent (42 percent) of its minimum economic (maximum) rate. While 63 percent of the aircraft programs operated above their minimum economic rate, only 31 percent of missile programs did so. These average statistics suggest that missile production is less efficient and this relative ranking is perfectly consistent with the relative rankings yielded by the regression results of this paper. This consistency can perhaps be interpreted as supporting the validity of the regression approach.

Third, the regressions which use aircraft and missile data together always yield lower values of β and lower t-statistics than do either of the regressions run on missiles or aircraft separately. There is a very clear economic reason for this. As explained above, the missile programs as a group exhibit lower utilization rates of all sorts than do the aircraft programs. However, the missile programs are on average much larger. From Table 2 the average aircraft program produced 36 units per year while the average missile program produced 2275 units per year. Therefore, when these two data sets are combined, the fact that the larger missile programs exhibit lower utilization rates pushes down the value of β. In fact for the case of U_{BIN} the value of β becomes mildly negative.

How one interprets this result depends upon whether one believes that a major difference in production technologies exists between missiles and aircraft which means that capacity utilization figures are non-comparable. If one believes that such a difference exists then the combined regressions should be ignored. However, if one believes that production technologies across the groups are not more variable than those within the groups, then the combined regressions strengthen the conclusions of this paper. On an economic level we observe the missile production occurs at very high volumes relative to aircraft production. Thus, the long run cost curve should have begun to "flatten-out" considerably at the rates missiles are produced. Therefore if production is occurring on the long run cost curve we should observe fewer reports of extremely steep short run average cost curves or large amounts of excess capacity. However precisely the reverse is true. It is for this reason that the combined regressions report lower values of β.

4. CONCLUSIONS

The starting point for this paper was a set of observations by the CBO on individual weapons systems regarding whether large amounts of excess capacity exist and whether SRAC appears to be severely decreasing. Neither of these observations are sufficient to demonstrate that production is not occurring on the long run cost curve. Both declining SRAC and excess capacity could simply be manifestations of the fact that there are long run economies of scale in weapons production.

This paper developed the idea that if the CBO observations were simply a manifestation of long run economies of scale then we would expect, on average, to see less excess capacity and fewer reports of steeply declining SRAC for systems being produced at higher rates. However it was shown that, over the crsoss-section of weapons systems analyzed by the CBO, the amount of excess capacity and steepness of SRAC were essentially independent of the observed output rate.

This suggests that inefficient production is in fact occurring. In particular, this suggests that CBO data identifying a particular weapons system as having large amounts of excess capacity and/or steeply declining SRAC can plausibly be interpreted as implying that production is occurring in an inefficiently large plant.

Finally, it should be noted that this paper perhaps leaves the most interesting questions unanswered. How large is the dollar loss due to inefficient scale choice? How significant are long run economies of scale in weapons production? Unfortunately there appears to be no way to address these questions without directly estimating both long and short run cost curves. Thus, although this paper was able to finesse the data availability issue to draw a limited conclusion, further progress will probably depend on the development of better publicly available data.

APPENDIX
ALTERNATIVE REGRESSION SPECIFICATION

The major qualitative conclusions of the empirical analysis of Section 3 were as follows:

(i) Although there is generally a very weak positive relationship between utilization rate and production rate this relationship is statistically insignificant for all three utilization rates (U_{MAX}, U_{MIN}, U_{BIN}) and all three data groups (aircraft, missiles, both).
(ii) Across data groups, the positive relationship is generally weakest for the combined sample of aircraft and missiles.
(iii) Across utilization rates the positive relationship is generally weakest for U_{BIN}. In fact U_{BIN} is very weakly (and insignificantly) negatively related to production rate in some cases.

The purpose of this appendix is to show that these results are robust to variety of alternative specifications for the regression equation.

Recall that the regression equation estimated in Section 3 for all three utilization rates was a simple linear specification of the form:

$$U_x = \alpha + \beta R \tag{7}$$

From a theoretical standpoint, the major problem with this specification is that it does not adequately deal with the fact that the utilization rates are either limited dependent variables or discrete qualitative variables. A different alternate specification is required for each utilization rate to correct for this. First consider U_{MAX}. The data suggests the U_{MAX} is always less than 100 percent. Thus it is probably appropriate to view U_{MAX} as a limited dependent variable in the range (0, 100). A simple specification which requires predicted values of U_{MAX} to fall in this range is given by:

$$\mathrm{LOG}_{MAX} = \alpha + \beta R \tag{8}$$

where LOG_{MAX} is defined by:

$$\mathrm{LOG}_{MAX} = \log\left(\frac{U_{MAX}}{100 - U_{MAX}}\right) \tag{9}$$

Now consider U_{MIN}. The data suggests that U_{MIN} will routinely exceed 100 percent. Thus it is probably appropriate to view U_{MIN} as a limited dependent variable with range $(0, \infty)$. A simple specification which requires predicted values of U_{MIN} to fall in this range is given by:

$$\mathrm{LOG}_{MIN} = \alpha + \beta R \tag{10}$$

where LOG_{MIN} is defined by:

$$\mathrm{LOG}_{MIN} = \log U_{MIN} \tag{11}$$

Finally consider U_{BIN}. This is a binary variable assuming the value 0 or 100. Thus a logit or probit specification is appropriate to account for this. The results of estimating the logit specification:

$$\mathrm{Prob}(U_{BIN} = 100) = \Lambda(\alpha + \beta R) \tag{12}$$

will be reported where Λ is the logit transformation. A probit specification was also run with virtually identical results.

One final type of alternative specification was considered. The specification of Section 3 and those described above were also all estimated using the log of R instead of R as the independent variable. This variable will be denoted by LOG R.

Table 4 t-Statistics for β for alternative regressions

Regression			*Data*		
Dependent variable	*Independent variable*	*Regression type*	*Aircraft*	*Missiles*	*Both*
U_{MAX}	R	Linear	1.68	0.95	0.79
U_{MAX}	LOG R	Linear	1.71	0.84	0.78
LOG_{MAX}	R	Linear	1.52	1.01	0.88
LOG_{MAX}	LOG R	Linear	1.54	0.94	0.85
U_{MIN}	R	Linear	0.16	0.75	0.74
U_{MIN}	LOG R	Linear	0.08	1.36	0.69
LOG_{MIN}	R	Linear	0.48	0.46	0.27
LOG_{MIN}	LOG R	Linear	0.23	0.89	0.16
U_{BIN}	R	Linear	0.42	0.18	−0.57
U_{BIN}	LOG R	Linear	−0.17	1.26	−0.94
U_{BIN}	R	Logit	0.44	0.19	−0.56
U_{BIN}	LOG R	Logit	−0.17	1.21	−0.95

Table 4 reports the t-statistic on β for all of the specifications (both the original ones of Section 3 and the alternative ones described here). This is the relevant statistic for determining the three qualitative properties described above. For each utilization rate there are four specifications. Thus there are twelve specifications in total. Since there are three data groups, the results of 36 regressions are reported.

Table 4 reports the results grouped by utilization rate. The first four lines report the results for regressions using the utilization rate U_{MAX}, the next four report the results for regressions using the utilization rate U_{MIN}, etc. The first row of each group reports the results for the original simple linear specification of Section 3. The next 3 rows report the results for the three alternate specifications.

The basic conclusion to be drawn from Table 4 is that none of the three qualitative conclusions are altered by considering the alternate specification. The t-statistics change very little either in magnitude or in relative rankings. None are significant in any of the alternate specifications. It is also the case that, for any given regression equation, the t-statistic for the combined data group using both aircraft and missiles is generally smaller than the t-statistics for the aircraft or missile groups. Finally, the t-statistics for the regressions involving U_{BIN} tend to be the smallest and are negative in many cases.

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