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Costly capital reallocation and the effects of government spending

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Abstract

Changes in government spending often lead to significant shifts in demand across sectors. This paper analyzes the effects of sector-specific changes in government spending in a two-sector dynamic general equilibrium model in which the reallocation of capital across sectors is costly. The two-sector model leads to a richer array of possible responses of aggregate variables than the one-sector model. The empirical part of the paper estimates the effects of military buildups on a variety of macroeconomic variables using a new measure of military shocks. The behavior of macroeconomic aggregates is consistent with the predictions of a multi-sector neoclassical model.

1 Introduction

Approximately one-fifth of U.S. GDP is purchased directly by the government. Fourteen percent of income is distributed and spent according to government laws on transfer payments. Government purchases and transfers

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are not uniform across sectors of the economy. For example, the government tends to purchase military hardware and (indirectly) purchase health care at rates higher than these goods' share in GDP. Even more important, changes in government spending are often accompanied by dramatic shifts in government spending in a few industries. During the defense builddown from 1987 to 1995, government defense spending on aerospace equipment, ships, and military vehicles fell by 79 percent.

In this paper we argue that accounting for the composition of government spending is important for understanding the aggregate effects of changes in government spending. Our argument is based on the presumption that it is costly to shift factors of production across sectors. There is already ample evidence that labor is not perfectly mobile across sectors, and our own work (Ramey and Shapiro (1998)) provides evidence on the costs of reallocating capital across sectors. Phelan and Trejos (1996) use a labor matching model to argue that the defense builddown led to the 1990-91 recession because of the sectoral shifts it produced. In a similar spirit, we suggest that an important part of the aggregate effect of changes in government spending is through shifts in demand across sectors of the economy.

Our findings bear on the much broader debate concerning the basic structure of the economy, since the effects of government spending are often used as a litmus test. Several authors (e.g., Rotemberg and Woodford (1992) and Devereux, Head, and Lapham (1996)) have maintained that only a model with imperfect competition and increasing returns to scale can explain the aggregate effects of government spending. Their arguments are based on empirical evidence suggesting that increases in government spending are accompanied by increases in consumption, real wages, and productivity. They conclude that the neoclassical model is not consistent with the data.

The two-sector neoclassical model can produce a much richer set of implications for the data than the standard, one-sector neoclassical model. In particular, it can produce some of the implications that were previously believed only obtainable in a model with imperfect competition and increasing returns. In our model some measures of real wages may rise and interest rates may fall in response to an increase in government spending. Furthermore, we find that the sectoral effects can lead to an attenuation of the negative wealth effect on consumption and a magnification of the wealth effect on hours. Therefore, this paper demonstrates that imperfect capital mobility can substitute for imperfect competition as a mechanism for producing predictions about business-cycle dynamics.

Moreover, we present new evidence that challenges the view that the data are fundamentally at odds with the neoclassical model. In particular, we show that following exogenous, sustained military buildups in the post-World War II period, consumption, real product wages, and manufacturing productivity fall. Furthermore, the behavior of additional variables, such as relative prices, different measures of the real wage, interest rates, and the composition of investment, is well-explained by our sectoral model of the impact of government spending.

The plan of the paper is as follows. After reviewing the relevant literature, we document how changes in government spending are often very sector specific. We focus most of our attention on military spending, as have many other papers in the literature, because of its exogeneity and because of data availability. We then present a modified version of the basic neoclassical model in which government spending changes are concentrated in one sector. The implied paths of key variables can be very different from the standard one-sector model. Finally, we present reduced-form empirical evidence on the effects of government spending. In evidence that runs counter to the conventional wisdom, we find that product wages, consumption, and manufacturing productivity fall in response to military buildups in the United States since World War II. Overall, the empirical results are consistent with our two-sector neoclassical model.

2 Previous work on the effects of government spending

There is a substantial literature that analyzes the effects of government spending on the economy. The neoclassical approach, as represented by the work of Hall (1980), Barro (1981, 1989), Aschauer and Greenwood (1985), Mankiw (1987), Aiyagari, Christiano, and Eichenbaum (1992), Christiano and Eichenbaum (1992), Baxter and King (1993), Braun and McGrattan (1993), and Finn (1995), analyzes the effects of government purchases in dynamic general equilibrium economies with no market imperfections. The more recent papers use models with capital accumulation and variable labor supply and reverse some of the results from the earlier models.

The main results from the most recent neoclassical models (e.g., Aiyagari et al. and Baxter and King) are as follows. Consider a permanent increase in government spending financed by nondistortionary means, and which does not directly alter the marginal utility of private consumption or the productive capital stock. The increase in government spending creates a negative wealth effect for the representative household. If both goods and leisure are normal goods, the household responds by both decreasing its consumption and increasing its labor supply. The increased labor supply lowers the real wage and drives up the marginal product of capital, which spurs investment. Real interest rates increase temporarily. In the new steady state, capital is higher, private consumption is lower, and the interest rate and the real wage return to their original values. Depending on the intertemporal elasticity of substitution in leisure, the output multiplier of government spending can exceed unity in the short run.

In contrast to the earlier models, the recent models predict that *temporary* increases in government spending have less impact on output than permanent increases. Because of the smaller wealth effect, labor supply increases less. Output and real interest rates also increase by less than in the permanent case. Furthermore, in many cases investment will decline temporarily.

Several papers have argued that the predictions of the neoclassical model are at odds with the data and propose New Keynesian models of the effects of government spending. For example, Rotemberg and Woodford (1992) maintain that contrary to the predictions of the neoclassical model, an increase in military spending raises output more than hours and raises rather than lowers the real wage. Rotemberg and Woodford propose a model with increasing returns and oligopolistic pricing that matches their data better. Similarly, Devereux, Head, and Lapham (1996) propose a model of monopolistic competition and increasing returns. The increasing-returns feature implies that an increase in government spending can raise productivity, wages, and private consumption. Thus, this type of model can explain the positive correlation between government spending and the Solow residual found by Hall (1988) and Evans (1992).

Despite the multitude of theoretical studies of government spending, the empirical effects of government spending have received far less scrutiny than the empirical effects of money. Most tests of these predictions have been isolated studies of either the relative effects of permanent and temporary changes in government spending (e.g., Barro (1981)), the correlation of government spending with consumption or Solow residuals (e.g., Hall (1988, 1990)), or the effects of government spending on real interest rates (e.g., Barro (1987, 1989), Evans (1987), and Plosser (1987)). There has been less systematic examination of the effects of government spending on the major macroeconomic aggregates. As a result, there is uncertainty about the stylized facts of the effects of government spending on aggregate variables. In the empirical part of this paper, we will offer results on the effects of military buildups on an important set of macroeconomic variables.

3 Changes in the composition of government spending

In this section we document that many of the significant changes in overall government spending are directed to a few subcategories of spending. We consider several military buildups as well as the highway construction program and the effect of medical transfer payments.

Consider first the four major military buildups of the last 60 years: World War II, the Korean War, the Vietnam War, and the Carter-Reagan buildup. In all of these periods, government spending on durable goods increased far more than other categories of spending. During World War II, when total government spending more than quintupled, spending on durable goods rose from 3 percent to 35 percent of total government spending. During the Korean War it rose from 9 percent to 19 percent; during the Vietnam buildup it rose slightly from 10 percent to 12 percent; and during the 1980s buildup, it rose from 9 percent to 14 percent. Thus, particularly during World War II and the Korean War, the share of spending that went to durable goods increased substantially.

Moreover, the increases in government spending on manufactured goods during a military buildup tend to be concentrated in only a few industries. We highlight this fact by comparing data from the Census of Manufacturers from 1977 (a trough in government military spending) and 1987 (a peak in government military spending). Seventy-two percent of the dollar increase in shipments to the government (both federal and state and local) was concentrated in the following industries: ordnance (SIC 348), engines and turbines (3511), communication equipment (3663, 3669), aircraft (372), ships (3731), missiles and space vehicles (376), tanks (3795), search and navigational instruments (3812), and laboratory equipment (3821). The dollar value of total shipments from these industries was 4.4 percent of total manufacturing shipments in 1977 and 7 percent in 1987. In 1987, two-thirds of the shipments from these industries went to the government. Thus, not only are government spending increases heavily concentrated in a few industries, but it is also the case that the government is the primary purchaser of goods from these industries. Furthermore, these numbers are lower bounds on the importance of the government because they do not include subcontracts (e.g., aircraft engines shipped to another company for assembly into military airplanes).

We also consider briefly the sectoral effects of the highway construction program and government transfers for health care. Congress authorized the National System of Interstate and Defense Highways in 1956, and the peak in spending on the program occurred in 1967. During that year, government purchases accounted for 32 percent of total final demand for new construction.[1] As spending diminished, the government share of purchases of new construction also decreased, falling to 23.5 percent in 1972, 20.9 percent in 1977, and below 20 percent thereafter. Thus, the spending cycle on this program represented an important part of the variation in demand for the construction industry.

While government purchases of health care are not a significant part of di-

[1]The data are from the input-output tables. New construction is industry number 11.

rect government purchases, the government indirectly purchases health care through its transfer programs, such as Medicare and Medicaid. Because reimbursement is received only for purchases of health care, this program heavily subsidizes the demand for health care. The combination of program changes, interacted with the changing demographic structure of the population, has led to significant long-run increases in indirect purchases of health care by the government. For example, in 1960 health care was 5.3 percent of GDP, and the government represented 21 percent of health-care expenditures.[2] Both percentages increased over time, so that as of 1990, health-care expenditures were 12.2 percent of GDP and the government paid for 40 percent of total health expenditures. It is likely that part of the increasing importance of the health sector in the economy is the result of government transfer payments. It is also likely that a reduction in government spending for Medicare would have a significant impact on the size of the health-services sector.

In sum, many of the important government spending and transfer programs are directed to very narrow sectors. Furthermore, variations in spending on those programs can represent important shifts in overall demand for the output of key industries.

4 A 2-sector neoclassical model of government spending

We now present several versions of a two-sector neoclassical model in which government spending is sector-specific. All versions of the model depart from the standard model by incorporating two sectors with costly mobility of capital between sectors. Within this framework, we consider the effects of variations in the production technology and the degree of capital specialization. Section 5 will present simulations using the model.

4.1 *Cobb-Douglas model*

We begin by specifying a model with a standard Cobb-Douglas technology and no variation in the utilization of capital. In the next subsection, we will present a model with a Leontief technology and variable utilization of capital. As we will see, this second model will lead to some differences in how the economy responds to shocks to government purchases.

Technology. Representative firms in each of two sectors produce with the same technology. The technology in each sector is given by the following

[2]The data are from the *Statistical Abstract.*

Cobb-Douglas function:

$$Y_{it} = AL_{it}^{\alpha} K_{it}^{\prime 1-\alpha}, \quad i = 1, 2 \tag{1}$$

where

Y_{it} = flow of output in sector i during period t,

L_{it} = total hours of employment in sector i during period t,

K'_{it} = stock of available capital in sector i during period t,

α is a parameter that lies between 0 and 1, and A is a positive parameter.

Firms in each sector can augment their capital stocks by buying either newly-produced investment goods or used capital from the other sector. New and used capital are both available with the same lag. New capital is not productive until one period after it is produced; in order to be shifted across sectors, used capital must spend one period being unproductive.

We add a further restriction that new capital goods for a particular sector must be produced within that sector. If new capital goods could be produced by either sector, then an increase in government demand in one sector would cause the second sector to take over investment goods production. This ability to shift production would effectively offset the sectoral shift in demand, and potentially cause the economy to behave as if there were only one sector. There are alternative ways to specify the model so that capital is effectively specific.[3] We choose the assumption that capital must be produced within the sector to capture the idea of specialization in capital goods production. The capital input-output tables suggest that many capital goods industries produce capital for only a few downstream industries. To capture this vertical integration aspect of capital goods production without adding more sectors, we collapse the upstream and downstream industries into one sector.

Finally, we assume that the value of existing capital falls when it shifts sectors. This fall in value occurs because a piece of capital has many characteristics, and only some of those characteristics are fully valued in the other sector.

These assumptions on the cost of shifting capital, which are at the heart of our model, deserve some discussion. Our study of capital reallocation from the aerospace industry serves as the basis for our assumptions (Ramey and Shapiro (1998)). We find that after taking into account any reasonable range of annual economic depreciation, equipment sold at prices that were

[3] Longer gestation lags would have a similar effect of preventing the output of one sector from being transferred quickly to the capital of the other sector. But they would also delay the adjustment of the capital stock within a sector.

half the price of similar new equipment. The case of a particular wind tunnel discussed in the newspaper provides a useful illustration (*San Diego Union-Tribune* Oct. 23, 1994). A low-speed wind tunnel capable of producing winds from 10 to 270 miles per hour was sold to a company outside of the aerospace industry. This company rents the wind tunnel for $900 an hour to businesses such as bicycle helmet designers and architects who wish to gauge air-flows between buildings. Most of the users require only low windspeeds, up to 40 miles per hour, and do not value the fact that the tunnel can produce 270 mile per hour windspeeds. Thus, a key characteristic of this wind tunnel - high air speeds - has no value outside of aerospace.

Our study of the aerospace industry also finds that there are important delays in the shifting of capital across sectors. The lumpiness of the decision to close a factory, as well as difficulties matching buyers to sellers, can lead to time delays. We assume a one-period delay. Long delays would lengthen the duration of the effect of sectoral shocks.

The equations that specify the evolution of capital stocks are as follows:

$$
\begin{aligned}
K_{it+1} &= (1-\delta)K_{it} + I_{it} - R_{it}, \quad i = 1,2 \\
K'_{it} &= K_{it} - R_{it}, \quad i = 1,2 \\
I_{1t} &= X_{1t} + (1-\gamma)R_{2t} \\
I_{2t} &= X_{2t} + (1-\gamma)R_{1t}
\end{aligned}
\tag{2}
$$

where

K_{it} = stock of capital in sector i at the beginning of period $t, K_{it} \geq 0$,

I_{it} = purchases of new and used capital goods by sector $i, I_{it} \geq 0$,

R_{it} = sales of capital by sector $i, R_{it} \geq 0$,

X_{it} = production of new capital goods by sector $i, X_{it} \geq 0$,

δ = geometric rate of depreciation, and

γ is a parameter between 0 and 1.

Capital is accumulated by investing in new capital goods X or by buying used capital goods from the other sector, R. The difference between a sector's capital stock, K, and available capital, K', is the capital that has been pulled out of production in order to be sold, R. The time lag is captured with the specification that R_{it} is deducted from available capital in period t, but cannot be used in sector j until period $t+1$. The γ parameter gives the fraction of the physical amount of capital that is lost when it shifts sectors.

Preferences. We assume that preferences take the following logarithmic form:

$$V = E_0 \sum_{t=0}^{\infty}(1+\rho)^{-t}\{log(C_{1t}) + \theta log(C_{2t}) + \phi log(T - L_{1t} - L_{2t})\} \quad (3)$$

where

C_{it} = consumption of good i in period t,

T = total time available,

L_{it} = total hours supplied to sector i,

E_0 = expectations based on information in period 0, and

ρ, θ, and ϕ are positive parameters, $0 < \rho < 1$.

Thus, our specification of preferences for this model is also quite standard, except for the addition of two consumption goods and labor supply to two sectors. We will modify this preference specification in the variable utilization model we present later.

Resource constraints. Government spending enters only through the resource constraints. Thus, we ignore distortionary taxation, substitutability of government consumption for private consumption, and government investment in capital. The economy's resource constraints are given as follows:

$$\begin{aligned} Y_{1t} &= C_{1t} + X_{1t} + G_{1t} \\ Y_{2t} &= C_{2t} + X_{2t} + G_{2t} \end{aligned} \quad (4)$$

The Gs stand for government spending in each sector, and as before Y is output, C is consumption, and X is newly-produced capital goods.

Macroeconomic equilibrium. Under the assumption of complete markets and no distortions, the competitive equilibrium of this economy corresponds to the solution of the following social-planner problem: Choose $\{C_{1t}, C_{2t}, L_{1t}, L_{2t}, K_{1t+1}, K_{2t+1}, R_{1t}, R_{2t} : t \geq 0\}$ to maximize (3) subject to equations (1), (2) and (4), and the initial position of the economy summarized by K_{10}, K_{20}.

4.2 *Leontief technology with variable capital utilization*

We now present a version of the model that differs in its specification of technology, and to some extent, its preferences. We feel that this model captures the short-run margins of production better then the Cobb- Douglas, and we wish to determine how the economy's response to government shocks differs from the more standard Cobb-Douglas model. The model is a general equilibrium version of a model analyzed by Lucas (1970).

Technology. We assume that at any moment in time capital and labor must be combined in fixed proportions. Firms can, however, vary the workweek of capital and labor, so that output can vary relative to the stock of capital in the short run. We make these assumptions based on our observations of production in manufacturing, where the scope for substituting capital and labor can be quite limited in the short run, but where variations in the workweek of capital are an important source of output fluctuations.

These ideas are captured in the following specification for technology:

$$Y_{it} = (1 + S_{it} - D_{it}) \cdot min(\frac{N_{it}}{\alpha_n}, \frac{K'_{it}}{\alpha_k}), \quad i = 1, 2, \tag{5}$$

where

Y_{it} = flow of output in sector i during period t,

N_{it} = number of workers employed at any instant in sector i during period t,

K'_{it} = stock of available capital in sector i at any instant during period t,

S_{it} = number of overtime hours or extra shifts hours that capital is in use in sector i during period $t, S_{it} \geq 0$,

D_{it} = number of hours of short weeks or shutdowns of capital in sector $i, D_{it} \geq 0$. αs are parameters.

The specification of technology implies that at any instant in time, workers (N) and machines (K) must be combined in fixed proportions; for example, one worker is combined with one machine. Thus, firms can increase output within the period only by increasing the workweek of capital. The workweek of capital is given by $(1 + S - D)$, where the standard 40-hour workweek has been normalized to unity, so that S and D are proportions relative to the standard week. Thus, if $S = 0.20$ and $D = 0$, then we might think of this as a 48-hour workweek of capital. We distinguish between adding shifts or overtime hours (S) and running short-weeks (D), although they have the same effect on output. When we specify preferences, we will assume additional disutility from shift or overtime work, but no disutility from short weeks.[4]

[4]Because our model is calibrated to give positive S in the steady state (to match the data), the results do not change in any of our simulations if we treat short weeks and shifts symmetrically. The main advantage of our specification is that it allows for free temporary disposal of capital.

We make the same assumptions regarding capital accumulation and transfers of capital between sectors that we did above. Thus, the equations in (2) also hold for this model.

Preferences. We augment the standard preferences specified above in (3) with a term that involves hours beyond the standard workweek. Government regulations specify an overtime premium of 50 percent for more than 40 hours of work per week. Union contracts also specify shift premia, but they tend to be on the order of five to ten percent. Shapiro (1995) argues that the shadow cost of capital utilization is higher than the nominal shift premium because employers must pay higher average wages to compensate for jobs that often involve shift work. Using cross-sectional evidence on wages and shifts, Shapiro (1995) calculates that the premium is at least 25 percent of the base wage. We capture these effects with the following specification of preferences:

$$\begin{aligned} V &= E_0 \sum_{t=0}^{\infty} (1+\rho)^{-t} \{ log(C_{1t}) + \theta log(C_{2t}) \\ &+ \phi log(T - L_{1t} - L_{2t}) - \sigma [N_{1t} S_{1t}^2 + N_{2t} S_{2t}^2] \} \end{aligned} \tag{6}$$

where

$$L_{it} = (1 + S_{it} - D_{it}) \cdot N_{it}.$$

Work hours can create disutility in two ways. The first effect, which is standard, is that an increase in hours supplied decreases leisure available, and the effect is the same whether it is through an increase in regular hours or extra hours. The second effect is captured by the last term in the utility function. This term, which is similar to the specification used by Bils and Cho (1994) and Bils and Klenow (1998), specifies that work during nonstandard hours generates increasing marginal disutility.[5]

We can interpret the extra hours as either overtime or extra shifts. In the overtime interpretation, N is the total number of workers, $(1 + S - D)$ is average hours per worker, and L is total hours supplied. The disutility of overtime is equal to the product of the number of workers affected (N) and a quadratic in the overtime hours per worker (S). Note that this specification implies that doubling the overtime hours per person generates greater marginal disutility than doubling the number of workers but keeping the overtime hours the same. On the other hand, in the shiftwork interpretation, N may be interpreted as the number of workers per shift (with equal numbers on each shift), $(1 - D)$ as the number of hours the day shift is operated, and S as the number of hours the night shift is operated. Suppose S

[5]There are alternative ways to induce a cost of increased utilization. For example, Finn (1995) assumes that increased capital utilization requires the use of energy at an increasing rate. Greenwood, Hercowitz, and Huffman (1988) and Burnside and Eichenbaum (1996) assume that increased capital utilization accelerates the rate of depreciation.

is one-quarter, which corresponds to the fraction of time U.S. manufacturing workers spend on late shifts. In our specification, this amount of shiftwork is generated by there being one night shift for every three day shifts with the night shifts operating at the same labor intensity as the day shifts. The specification of preferences implies that the disutility of night shifts is a function of the number of workers per shift and the number of hours that extra shifts are operated. In the representative agent model, the interpretation of preferences is clearest if workers rotate shifts, so that S is the proportion of time spent on the night shift relative to the day shift.

Macroeconomic equilibrium. Again assuming complete markets and no distortions, the competitive equilibrium of this economy corresponds to the solution of a social-planner problem: Choose $\{C_{1t}, C_{2t}, N_{1t}, N_{2t}, S_{1t}, S_{2t}, D_{1t}, D_{2t}, K_{1t+1}, K_{2t+1}, R_{1t}, R_{2t} : t \geq 0\}$ to maximize (6) subject to equations (2), (4), and (5) and the initial position of the economy, summarized by (K_{10}, K_{20}). Note that in the optimal solution to the social-planner problem, $N_{it} = \frac{\alpha_n}{\alpha_k} K'_{it}$ and $L_{it} = (1 + S_{it} - D_{it}) \cdot N_{it}$ by the nature of the technology. Furthermore, it will never be optimal to choose both D and S positive in a given sector.

4.3 *Calibration and steady state*

We choose parameter values so that the models match several key aspects of the economy. We begin by discussing the parameters that are common to other models. The weight on the log of leisure, φ is set equal to 2. We normalize the time endowment to be 200, and set the discount rate (ρ) to .04, since each period corresponds to one year. The annual depreciation rate δ is assumed to be 0.1.

We choose the α's and A so that both economies have similar outputs and capital in steady state. For the Cobb-Douglas production function, we set α equal to 0.75 and A equal to 0.5, giving a steady-state capital-output ratio of 1.8. For the Leontief production function, we set both α_n and α_k equal to 2, so that with steady-state shift use, the capital-output ratio is 1.6.

Sector sizes. In the simulations of Section 5, we study the effect of an increase in government spending with the magnitude and composition of that of the Korean War. We choose parameter values to produce an initial steady state that approximates the U.S. economy just before the Korean War in terms of the sizes of the two sectors and the importance of government spending in the two sectors, and parameterize the model so that the second sector is the one that faces all of the increase in government spending during the military buildup. To approximate the sizes of the sectors, we use input-output tables to estimate the fraction of output of various industries that is purchased by the Federal Government. We use the 1958 input-output tables because they are the earliest ones available and represent a time of relatively low military spending. Adding both direct and indirect purchases by the Federal government, we identify eighteen industries that sent fifteen percent or more of their shipments to the Federal government. Table 1 lists the industries and their value added. As shown at the bottom of the table, these industries accounted for 6.65 percent of value added in 1958, and purchases (direct or indirect) by the Federal government accounted for 41.6 percent of their sales.

Table 1:
Major Suppliers to the Federal Government
From the 1958 Input-Output Tables

Industry (Numbers represent Input-Output Industry codes)	Value Added (Billions of dollars)	Percent of Value Added Purchased by Federal Government
Nonferrous Metal Mining (6)	474	35.6
Ordnance (13)	1,622	86.7
Primary Nonferrous Metal Manufacturing (38)	2,848	22.3
Stampings (41)	1,632	18.2
Engines and Turbines (43)	932	19.7
Materials Handling Machinery (46)	402	17.2
Metal Working Machinery (47)	1,856	20.6
General Industrial Machinery (49)	1,632	15.3
Machine Shop Products (50)	851	39.0
Electric Industrial Equipment 953)	2,539	17.0
Radio, TV, and Communications (56)	2,680	40.7
Electronic Components (57)	1,317	38.9
Misc. Electrical Supplies (58)	655	15.1
Aircraft and Parts (60)	5,994	86.7
Other Transportation Equipment (61)	1,438	20.9
Scientific and Controlling Instruments (62)	1,642	30.2
Optical and Photographic Equipment (63)	842	15.1
Research and Development (74)	410	97.4

Note: These industries account for 6.65 percent of aggregate value added. Purchases by the Federal Government constitute 41.6 percent of their output.

In order to match the sectors in our model to these sizes, we set the weight on $log(C_{2t}), \theta$, equal to .05. We also set government spending in the first sector, G_1, equal to 7 and G_2 equal to 1. These values will produce a steady state that matches the data well.

Capital reallocation losses. We also require a value for the fraction of capital that is lost when it crosses sectors, γ in equation (2). We initially set this parameter to 0.5, meaning half of the physical stock of capital is lost when it changes sectors. As mentioned above, we found that used aerospace equipment sold at prices that were less than half the price of similar new equipment, even after taking vintage into account (Ramey and Shapiro (1998)). There is not a one-to-one correspondence between physical loss and price discounts. As long as the declining sector demands some capital, the price discount will be less than the physical loss. The value of the price discount depends not only on the physical loss, but also on the slope and shift of the demand curve. As we will see in the simulations, the value of the price discount varies when the production technology varies. Although we believe that $\gamma = 0.5$ is a reasonable value of γ, we will also show simulations in which $\gamma = .25$, so that only 25 percent of the value is lost.

Shift and overtime premia. The final parameter that must be calibrated is the disutility of shifts, σ, in the model with Leontief technology and variable capital utilization. As discussed above, Shapiro (1995) has estimated the marginal implicit cost of shifts to be at least 25 percent above the base wage.[6] Furthermore, Shapiro (1996) shows that manufacturing production workers spend, on average, about one-quarter of their time working nights. We use this fact to calibrate the average value of S, the fraction of hours worked beyond the standard workweek. To obtain an expression for the shift premium, we must consider the decentralized representative household optimization problem. In the model, the household receives different wages depending on the time of day of work. The labor income of the household in period t can be expressed as

$$Labor\ \ income\ = W_{b1t}(1+\lambda_{1t}S_{1t}-D_{1t})N_{1t}+W_{b2t}(1+\lambda_{2t}S_{2t}-D_{2t})N_{2t} \quad (7)$$

where W_{bit} is the straight-time wage and λ_{it} is the shift premium in sector i. Labor income consists of the sum of the wage bill in the two sectors. Workers are paid a base rate of W_{bit} per hour for regular hours and $W_{bit} \cdot \lambda_{it}$ for overtime or night-shift hours.[7] The values of the wages are found by solving the household's first-order conditions for optimal N and S.

To produce values for S and λ that fall within the range of the estimates given above, we set σ to 0.01, which in steady state will produce a shift or overtime premium of 38.8 percent and total hours that are 26.6 percent above straight-time hours. Table 2 summarizes the calibration of the parameter values.

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[6]The statutory overtime premium in the U.S. is 50 percent of the straight-time wage, but Trejo (1991) shows that this is not wholly allocative.

[7]Recall that an "hour" is actually a 40-hour workweek.

Table 2:
Numerical Values of Parameters for Simulations

Parameters (common to both models)	Values	Parameters (model-specific)	Values
θ	0.05	α	0.75
φ	2	A	0.5
T	200		
δ	0.1	α_n	2
ρ	0.04	α_k	2
γ	0.5 or 0.25	σ	0.01

Steady state. The steady-state solution to the social-planner problems described above are given in Table 3. Several characteristics are worth noting. First, the second sector is relatively small, representing 6.7 percent of total output, the number we calculated based on the 1958 input-output tables. Also in line with our calculations, government spending represents 39 percent of purchases from the second sector. For the model economy as a whole, government spending is 21 percent of output.

In the Leontief model, our calibrated parameters give equilibrium shift use that roughly matches the U.S. economy. In both sectors, firms set shifts to 0.266. The equilibrium marginal shift premium, inferred from the first-order conditions of the household, is 38.8 percent. This number lies between Shapiro's (1995) lower bound for the shift premium and the mandated premium for overtime. It is never optimal to underutilize capital or shift it across sectors in the steady state. The values of D and R reflect this fact.

5 The simulated effect of a military buildup

In this section, we show the results of numerical simulations of a sector-specific increase in government spending. Because the Korean War represents an important episode in our empirical results later in the paper, we study the effect of an increase in government spending of similar scale. The Korean War is also paradigmatic for a sharp, exogenous increase in government spending. Demobilization following World War II was substantial. The Korean War was the signal event - at least as far as spending was concerned - of the onset of the Cold War.

It is difficult to obtain information on the key defense industries during the

Table 3: A
Steady-State Values for Cobb-Douglas Model

Variable	Value	Variable	Value
G_1	7	G_2	1
Y_1	35.232	Y_2	2.553
K_1	62.914	K_2	4.559
L_1	73.177	L_2	5.302
C_1	21.940	C_2	1.097
X_1	6.291	X_2	0.456
R_1	0	R_2	0
P_2/P_1	1		

Table 3: B
Steady-State Values for Leontief Model

Variable	Value	Variable	Value
G_1	7	G_2	1
Y_1	35.847	Y_2	2.564
K_1	56.611	K_2	4.050
S_1	0.266	S_2	0.266
D_1	0	D_2	0
L_1	71.694	L_2	5.128
C_1	23.186	C_2	1.159
X_1	5.661	X_2	0.405
R_1	0	R_2	0
P_2/P_1	1		

early 1950s, so we loosely calibrate the increase in spending to the increase in Federal spending on durable goods, which tended to be concentrated on a few industries. Hostilities broke out in Korea at the end of June 1950. Federal purchases of durable goods were fifty percent higher during the following four quarters, and more than three times higher in the second year after the shock. They remained high through the second quarter of 1953, and then fell slowly. By the second quarter of 1957, they were still three times their initial level.

Although Federal spending on durables fell from its peak in 1953, it remained higher than before the Korean War. Military spending moved to a somewhat permanent, higher plateau because of the Cold War. Even if we adjust the increase in Federal government spending on durables to account for a four-percent annual rate of increase of GDP, durables spending was still more than twice as high in 1957 as in early 1950.

Figure 1, which is patterned after the Korean War, shows the path of government spending we use to drive the simulations. Note that the simulations are on an annual basis. For simplicity, we assume that government spending in sector 1 stays constant.[8] We also assume that the initial change in government spending is unforeseen, but that once the shock occurs, the time path of government spending is perfectly foreseen. These simulations only examine the impact of an increase in the demand for goods. They ignore the macroeconomic effects of conscripting or otherwise employing military personnel. Hence, while we believe the simulations realistically capture the effects of a sector-specific increase in government demand, which is the main topic of this paper, they do not capture all the impact of a military mobilization.

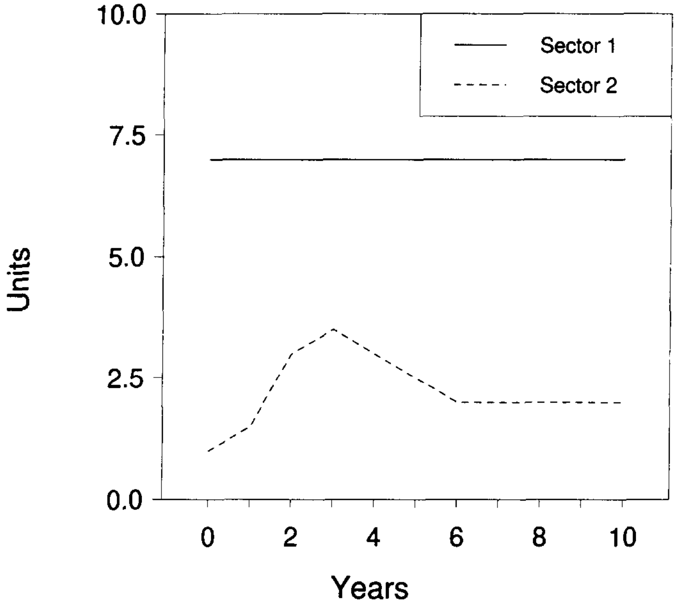
5.1 *Cobb-Douglas technology with 50-percent loss of capital*

The first results we consider are those from the Cobb-Douglas specification in which capital loses fifty percent of its value when it shifts sectors (γ equal to 0.5). Recall that there is also a time lag of reallocating capital: capital must be out of production for one year in order to be shifted. We compare the results from this model with those of a frictionless model in which capital can instantaneously and costlessly shift sectors, which is essentially a one-sector model.

Before discussing the aggregates in the graphs, we discuss several sectoral results not shown directly in the graphs. First, the experiment, which increases overall output, also constitutes a sectoral shift away from sector 1 to sector 2. Thus, output of sector 1 declines, while output of sector 2 rises.

[8] In reality, several other components of government spending, such as compensation of military personnel, increased while other components, such as state and local spending, decreased.

Figure 1. Simulated Military Buildup:
Time Path of Government Purchases by Sector



Note: The figure shows the time path of government purchases used in the simulations reported in Figures 2, 3 and 4.

Second, with γ equal to 0.5, shifting capital is so costly that none shifts in equilibrium. Thus, this experiment is identical to one in which capital is completely irreversible. We will show results later in which some capital does shift sectors.

Figures 2A-2B show the paths of various aggregates and price ratios.[9] The aggregate variables are constructed by summing components across sectors using base-year prices. For example, aggregate output is equal to the sum of Y_1 and Y_2 evaluated at base-year prices, when the price ratio is unity. Figures 2A-2B contrast the model with costly capital mobility (solid line) and frictionless capital mobility (dashed line). In the frictionless model, capital can adjust across sectors with no cost and with no lag.

The top two panels of Figure 2A show that costly capital mobility has little impact on the results for aggregate output and private output in the Cobb-Douglas model. Output rises and returns to a new permanently higher level. The impact effect on private output is positive, indicating a short-run government spending multiplier that is greater than unity. Beginning in the second period, private output falls below its starting pre-shock level. As shown by Baxter and King (1993), even without frictions the neoclassical model can generate positive impacts on output and large short-run multipliers.

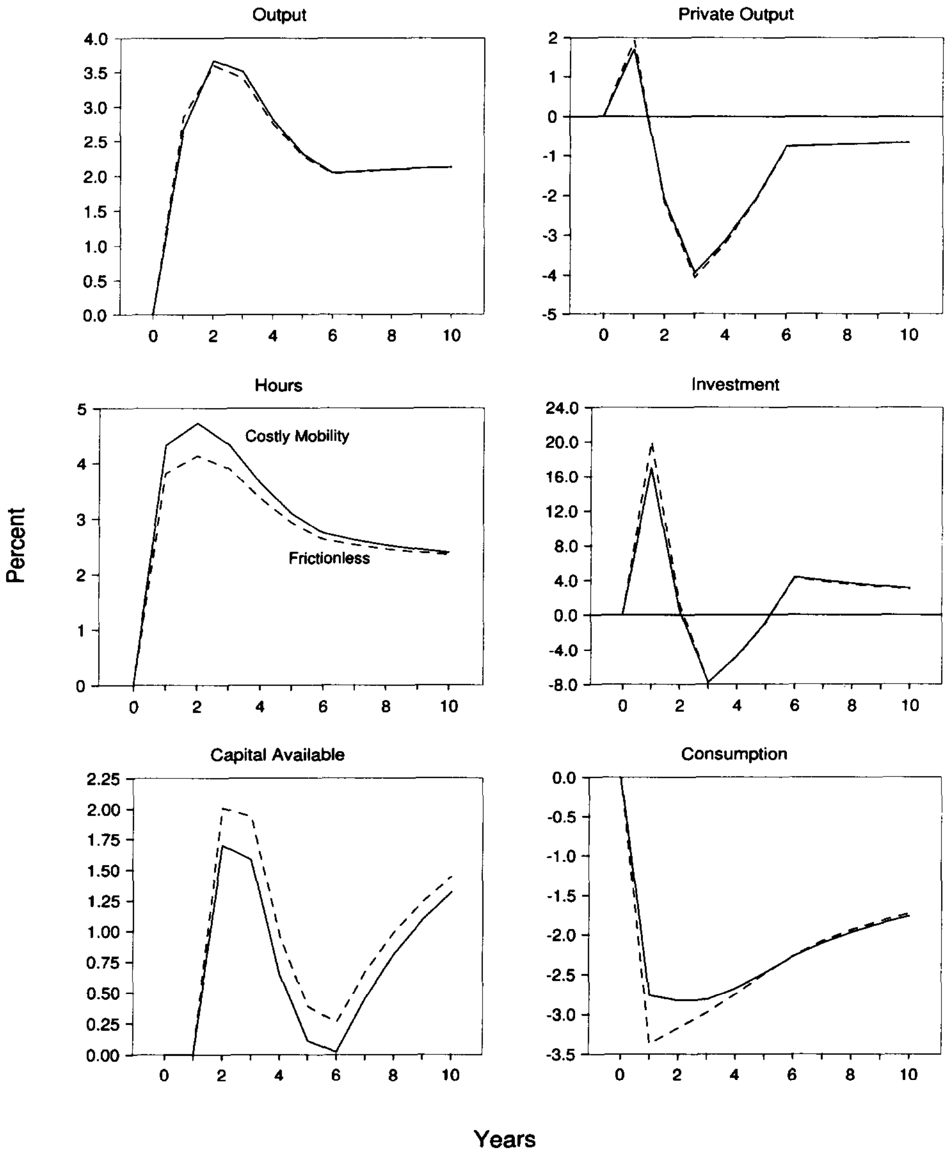
Other variables reflect noticeable effects of the frictions. The middle left panel of Figure 2A shows how the positive impact of government spending on hours is magnified some 15 percent with capital mobility frictions. This magnification stems from the additional negative wealth effect resulting from the cost of capital mobility. The sectoral shift induced by the increase in government spending reduces the value of the capital stock. Although the capital evaluated at base-year prices does not decrease, the current value of capital falls owing to the misallocation of capital across the two sectors.

We do not display a separate graph showing the effect on productivity, but a comparison of the hours and output graphs clearly shows that labor productivity declines in both cases. As one would expect, the decline in productivity is greater in the model with frictions.

The graph of investment (production of new capital) and capital available for production (the capital stock less the capital in transit between sectors) in Figure 2A shows the extent to which the economy without frictions can better deploy its capital. Recall that the capital must be produced in the same sector in which it is used in the economy with frictions. Sector 2, which is already encountering diminishing marginal product of labor because of the increase in government demand, must also increase its output of new investment goods. In contrast, sector 1 decreases its output of new investment goods. Without frictions, some of sector 1's output is devoted to producing

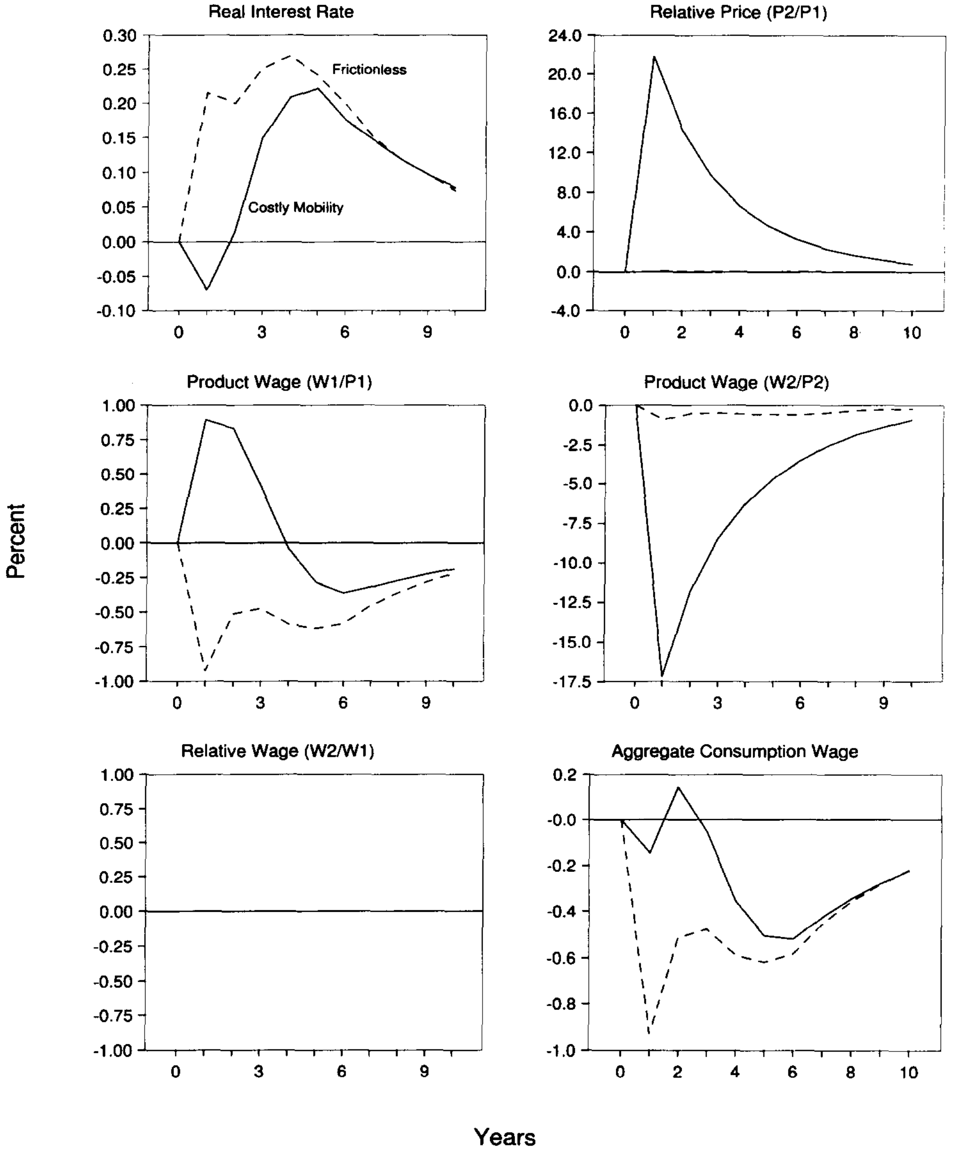
[9] All simulations were performed using the GAMS program.

Figure 2A. Simulated Response to a Military Buildup: Cobb-Douglas Technology, Frictionless versus High-Cost Capital Mobility



Note: Figure reports simulated response to the military buildup shown in Figure 1 assuming the Cobb-Douglas technology. The solid line shows simulations with high-cost capital mobility (γ=0.5). The dashed line shows simulations with frictionless capital mobility. See text for details.

Figure 2B. Simulated Response to a Military Buildup: Cobb-Douglas Technology, Frictionless versus High-Cost Capital Mobility



Note: Figure reports simulated response to the military buildup shown in Figure 1 assuming the Cobb-Douglas technology. The solid line shows simulations with high-cost capital mobility (γ=0.5). The dashed line shows simulations with frictionless capital mobility. See text for details.

capital for sector 2.

The behavior of consumption, shown in the last panel of Figure 2A, differs across the two cases. The frictionless model shows the decline and slow return of consumption to a new, lower steady state, typical of the standard neoclassical model. In contrast, aggregate consumption in the costly capital mobility model falls gradually for several periods, and then slowly rises to the new steady state. The less drastic fall of consumption in the costly capital mobility model owes to the limited opportunities to use foregone consumption as investment goods. Foregone consumption of good 1 cannot be used directly as investment goods in sector 2 since capital is "trapped" in the first sector. Some labor shifts from sector 1 to sector 2, but the diminishing marginal product of labor in the second sector limits the labor reallocation. Thus, consumption of good 1 falls slowly, since capital accumulation in sector 2 is slow. Because aggregate consumption is mostly composed of good 1, aggregate consumption follows a similar pattern.

The first panel of Figure 2B shows the implied path of real interest rates in the two models. Defining an interest rate is somewhat tricky in a two-sector model. We define interest rates using the growth rate of aggregate consumption, where consumption is aggregated using base-period prices. The frictionless model shows the standard neoclassical increase in real interest rates in response to the increase in government spending. In the costly capital mobility model, on the other hand, real interest rates as defined here actually drop for a period before rising somewhat and then returning to their original levels. Within sectors, the interest rate defined in terms of good 2 rises, but the interest rate defined in terms of good 1 falls. Thus, the capital immobility can actually reverse the interest-rate implications obtained from the one-sector model. The demand for capital is high in sector 2, but the bulk of aggregate consumption consists of good 1, which cannot be converted easily into capital in sector 2.

The remainder of the graphs in Figure 2B show various wage and price ratios. Consider first the relative price of the two goods. In the model without frictions, there is no change in the relative price of the two goods, since capital can shift immediately and costlessly. In contrast, the relative price of good 2 rises in response to an increase in relative demand when capital cannot shift costlessly. Note that this price ratio is also the relative price of capital in the two sectors. Recall that we discussed earlier the distinction between the physical loss of capital and the decline in its value. Although the assumed physical loss of capital is fifty percent, the relative decline in value of capital in the contracting sector (sector 1) is only 20 percent in this experiment. We will see later that this effect changes when the production function is different.

We also show the product wages in each sector, W_1/P_1 and W_2/P_2. In the model without frictions, both wages (which are equal) decline. The wealth effect raises labor supply, so the economy moves along a given labor-demand curve to a point with higher hours and lower product wages. The effects are more complicated in the two-sector model. The product wage in sector 1 rises, since the sector is moving to a point with fewer hours, whereas the product wage in sector 2 falls since hours rise. Thus, in both sectors hours and product wages move in opposite directions as they should with a shift in labor supply. The difference in the behavior of product wages across sectors owes entirely to changes in the relative prices. As the lower left panel shows, the relative wage across sectors remains constant.

The final graph in Figure 2B shows a consumption wage. We calculate this wage as follows. First, we calculate price and wage levels in dollar terms by setting the nominal value of consumption equal to a fixed stock of money, chosen so that the prices in the base year are equal to unity. Second, we construct a CPI index of the two prices, using the base-year consumption fractions as weights. Thus, the weight on the price of good 1 is 0.952. Finally, we construct an aggregate consumption wage by dividing total payroll by total hours and the CPI.

The results on the consumption wage are rather surprising. In the frictionless case, the real consumption wage declines, as one would expect from an increase in labor supply. In contrast, the real consumption wage rises above its initial level in the second year when there is costly capital mobility. The intuition for this result is as follows. Most of consumption consists of the first good, whose relative price has fallen. In contrast, a higher fraction of workers (though still a minority) is employed in the second sector, which bids up the economy-wide wage relative to the price of good 1.[10] Rotemberg and Woodford (1992) show in an economy with imperfect competition that a similar measure of the real wage can increase in response to a positive shock to government spending. Our result shows that similar dynamics can arise in an economy with perfect competition, but more than one sector.

5.2 *Leontief technology with 50-percent loss of capital*

We now present the results from the model with the Leontief technology and variable shifts, as outlined in equations (5) and (6) above. All of the aggregate variables are defined as in the last section. The only complication added by the model change is in the definition of product wages. Because of the distinction between wages by shift, the average wage must be calculated

[10]If we use a fixed-weight GDP deflator instead, the real wage follows the same type of pattern, but remains below the initial level.

as

$$\frac{W_i}{P_i} = \frac{W_{bi}(1 + \lambda_i S_i - D_i)N_i}{P_i(1 + S_i - D_i)N_i}. \tag{8}$$

The numerator is the wage bill in sector i and the denominator consists of the product of the price of output in sector i and the total hours in sector i. We obtain values for wages and prices from the first-order conditions of the representative household problem discussed in an earlier section.[11]

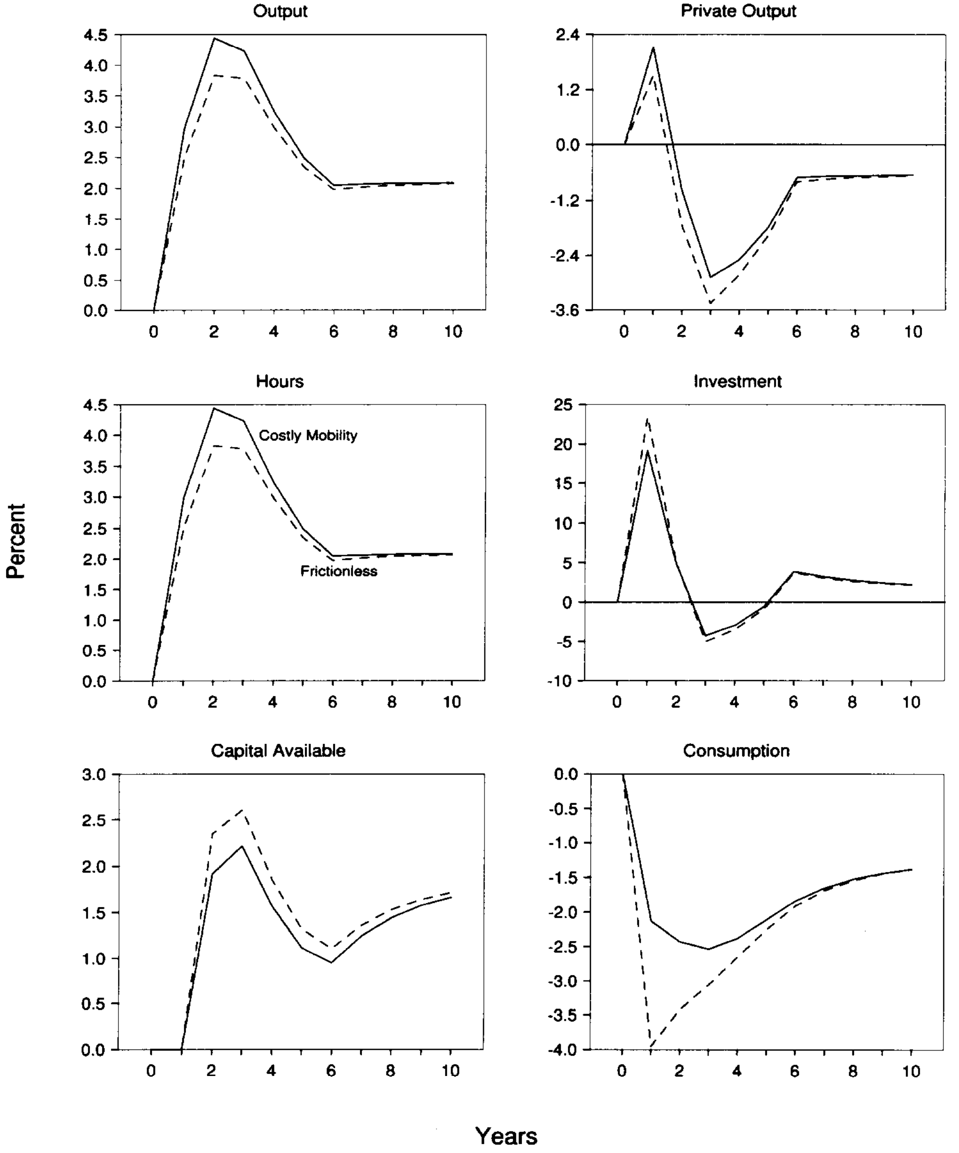
The Leontief technology limits substitution possibilities between capital and labor relative to the Cobb-Douglas case. Even though firms can choose to change capital utilization, the increasing marginal cost in the form of disutility of shifts limits its use. Thus, the effects of the frictions will be greater for some variables. The other difference between the two models is in the link between productivity and wages. Whereas the Cobb-Douglas technology with no shift use provides a simple link between marginal and average productivity and product wages, the link in the Leontief case is more complicated. The average productivity of labor is constant because of the fixed proportions assumption. On the other hand, the average product wage, which is a function of the base wage, shift use, and the shift premium, can vary widely based on changes in these underlying variables.

Figures 3A-3B show the results of the simulation with the Leontief technology. Again, we compare the case of costly capital mobility ($\gamma = 0.5$) to the frictionless case where capital moves costlessly and with no lag. The first difference to note is the magnification of the output effect. Recall that capital mobility costs had little impact on the output response relative to the frictionless case with the Cobb- Douglas technology. In contrast, the frictions magnify the output response by about 20 percent in the Leontief case. The reason is as follows: in both the Cobb-Douglas and Leontief cases, capital frictions magnify the hours response (somewhat more so in the Leontief case), but because marginal productivity is constant in the Leontief case output is magnified by the same amount. Thus, even though the second sector is a very small part of the economy, starting at just 6.7 percent of total output, the additional wealth effects resulting from the immobility of capital across sectors can lead to a noticeable magnification effect on total output.

The second difference is the behavior of consumption and the interest rate. Capital frictions produce a greater impact on consumption in the Leontief case than in the Cobb-Douglas case. In the Leontief model, consumption falls only half as much when capital mobility is costly. Thus, costly capital mobility magnifies the wealth effect on hours and attenuates the wealth effect

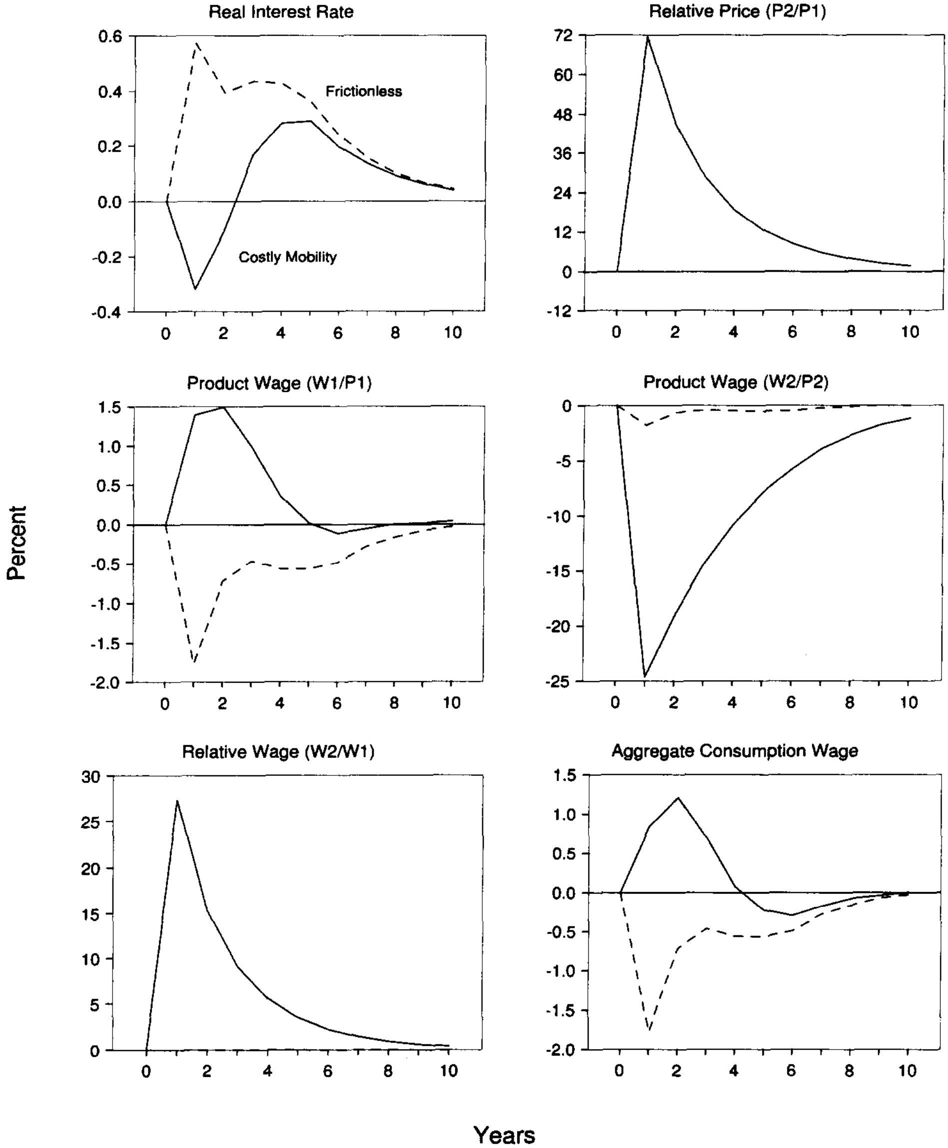
[11] In the maximization problem, the wage per worker adjusts in each sector to compensate the workers for the disutility of work - including the extra disutility associated with work on shifts. The shift premium in equation (8) is defined implicitly from the wage bill and the level of shifts.

Figure 3A. Simulated Response to a Military Buildup: Leontief Technology, Frictionless versus High-Cost Capital Mobility



Note: Figure reports simulated response to the military buildup shown in Figure 1 assuming the Leontief technology. The solid line shows simulations with high-cost capital mobility (γ=0.5). The dashed line shows simulations with frictionless capital mobility. See text for details.

Figure 3B. Simulated Response to a Military Buildup: Leontief Technology, Frictionless versus High-Cost Capital Mobility



Note: Figure reports simulated response to the military buildup shown in Figure 1 assuming the Leontief technology. The solid line shows simulations with high-cost capital mobility (γ=0.5). The dashed line shows simulations with frictionless capital mobility. See text for details.

on consumption. As discussed in the last section, the difficulty of reallocating resources from sector 1 to sector 2 implies that there is reduced incentive to forego consumption of good 1. The implied change in interest-rate behavior is even stronger in the Leontief case. The top panel in Figure 3B shows that interest rates fall and remain below their starting point for several periods before rising.

As for new investment and capital accumulation, the effects of the capital friction are also greater in the Leontief case. Like the Cobb-Douglas case, though, the capital friction makes the sectoral transfer of capital prohibitive.

Turning to relative prices and wages, shown in Figure 3B, we note several similarities and differences. First, the qualitative behavior of relative prices and product wages is the same as the Cobb-Douglas case. Because of the limited substitution possibilities and the variable shift premium in the Leontief case, the quantitative impact is higher. Relative prices of goods move much more in the Leontief model than they did in the Cobb-Douglas model. Differences between the Leontief model and the Cobb-Douglas model also arise in the behavior of the consumption wage and relative wages. The aggregate consumption wage in the Leontief case shows a sustained increase relative to small up-tick in the Cobb-Douglas model. The wage in sector 2 rises relative to the wage in sector 1 because firms need to pay a shift premium to increase the utilization of capital. The dramatic increase in the shift premium in sector 2 raises the average wage paid relative to the CPI.

In standard models with no variation in the workweek of capital, wages are equalized across sectors. Our specification of technology and preferences allows wages to be different across sectors (out of steady state) even though labor is perfectly mobile across sectors. Thus, our model with shift premia and costly mobility of capital produces results that look like the results from a model with costly mobility of labor. That sector 2 is paying a shift premium and that sector 1 is not introduces an inter-industry wage differential even though labor is free to move across sectors.

In sum, the Leontief model produces qualitatively similar results to the Cobb-Douglas model for many variables. In most cases, though, the difference between the response in the frictionless case and the costly capital mobility case is greater with the Leontief technology. With no margin for changing capital intensity, the ex post misallocation of capital has a greater impact on output. To allow output to respond to the higher demand in sector 2, we introduced the possibility of increasing capital services by using more capital hours. The shift premium needed so that workers will supply shiftwork has a substantial impact on relative and aggregate wages.

5.3 *Leontief technology with 25-percent loss of capital*

We now consider the impact of the same type of military buildup in an economy in which there is only a 25-percent loss of capital when it shifts sectors. In this section, we compare this medium-cost capital mobility case (corresponding to $\gamma = 0.25$) with the high-cost case ($\gamma = 0.5$) presented in the last subsection.[12]

Figure 4 shows graphs comparing the responses of output, capital available, new investment, and interest rates in the high- and medium-cost mobility cases. The key difference between the two cases arises with the capital available. With the medium cost of capital mobility, capital actually shifts from sector 1 to sector 2. Recall that with the high-cost case, the costs are so prohibitive that no capital shifts sectors. Because the capital is not available for production during the period it shifts, capital availability falls in the first period. Moreover, 25 percent of the capital that shifts is destroyed. (See dashed line in the bottom left panel of Figure 4.)

These differences in capital reallocation have effects on the other variables shown. As a result of the immediate decline in available capital, output in the medium-cost case rises less initially than in the high-cost case. Interest rates behave much like in the frictionless model, since now there is more scope for transforming today's foregone consumption of good 1 into sector 2 capital. We do not include graphs of relative wages and prices. Their movements are qualitatively similar to those for the model of the last section, but are less dramatic.

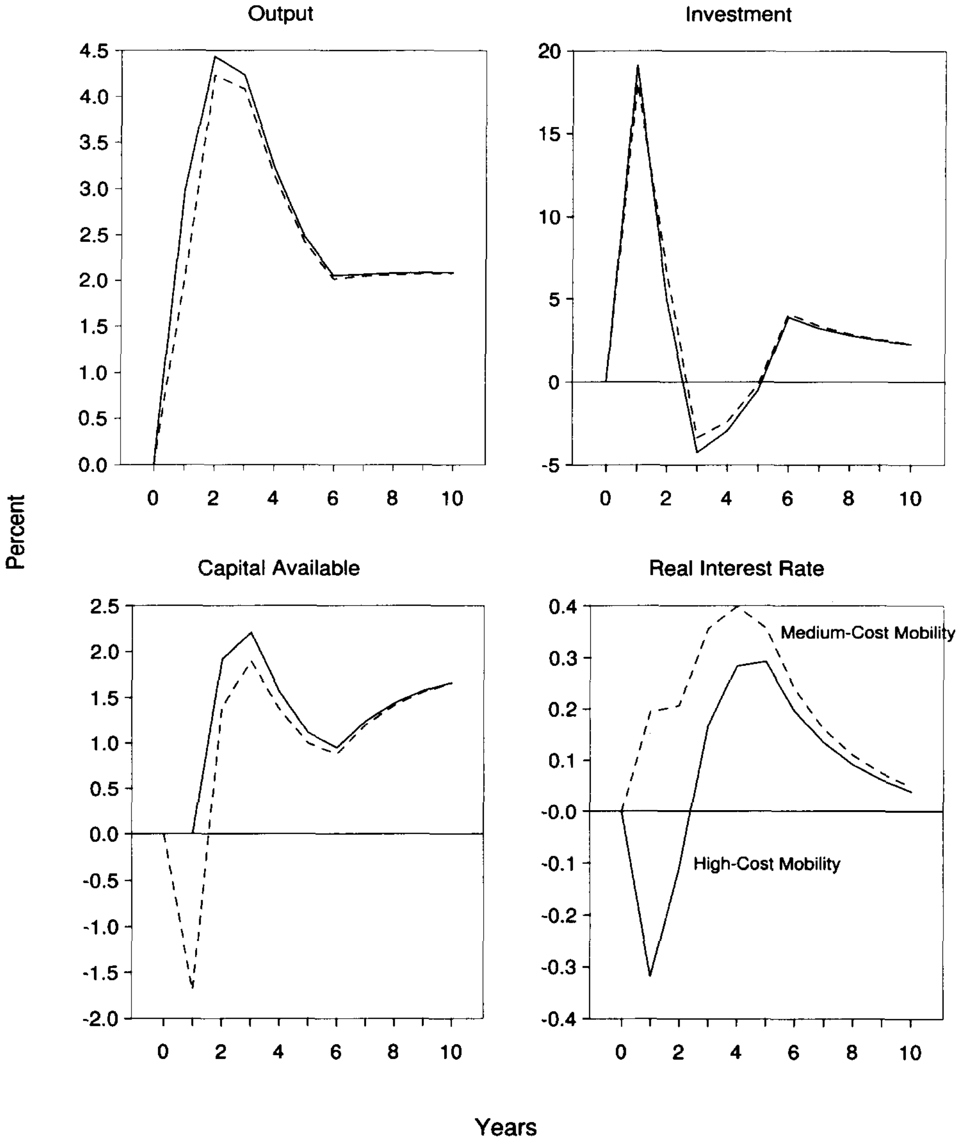
5.4 *Summary of the effects of a military buildup*

Although it is difficult to draw general conclusions from specific calibrations and simulations, the results do suggest that the impact of capital frictions is greater when the substitutability of capital and labor is more limited. While the Cobb-Douglas case is probably a better approximation for the time span in which firms can choose new technologies, we believe that the Leontief technology with a variable workweek of capital is probably a better approximation for the short-run substitution possibilities in many industries.

Costly capital mobility can lead government spending increases to have very different aggregate effects than they would in a one-sector model. Costly capital mobility can magnify the effect on output and employment and lead to temporarily lower rather than higher real interest rates. Furthermore, the behavior of wages and prices differs significantly across sectors. While product wages and hours move in opposite directions within sectors, the

[12] We do not present the medium-cost case for the Cobb-Douglas technology. Even with $\gamma = 0.25$, there is no shifting of capital across sectors in the Cobb-Douglas case.

Figure 4. Simulated Response to a Military Buildup: Leontief Technology, Medium-Cost versus High-Cost Capital Mobility



Note: Figure reports simulated response to the military buildup shown in Figure 1 assuming the Leontief technology. The solid line shows simulations with high-cost capital mobility (γ=0.5). The dashed line shows simulations with medium-cost capital mobility (γ=0.25). See text for details.

aggregate consumption wage may move in the same direction as aggregate hours. This latter effect occurs despite the fact that there is no shift in labor demand.[13]

6 Empirical evidence of the effects of military buildups

The preceding sections highlight theoretically the importance of taking into account the differential effects of government spending across sectors. In this section, we use military buildups to investigate these effects empirically. Military buildups represent an excellent laboratory for studying shocks to demand that move resources from one sector to another. First, apart from the military employment, which removes resources overall from the private sector, demand on private-sector resources from a military buildup is heavily concentrated in the manufacturing sector. Second, military buildups occur rapidly and unexpectedly, so they are naturally modeled as shocks.[14] Third, military buildups, because they are driven by imperatives of foreign policy, are less likely to affect private technology or to substitute for private consumption than other big spending programs.[15] Fourth, again because they are driven by geo-political shocks, military buildups are likely to be exogenous with respect to macroeconomic variables.

We study the military buildups of the post-World War II period. We decided to omit World War II because other forces, such as the impact of patriotism on labor supply and the effects of price controls, may have been important and therefore confound the types of effects we wish to study. We include the Korean War because the patriotism effects do not seem very important (*Business Week*, August 5, 1950, p. 9), and because price controls appeared not to be very rigid (*Business Week*, May 3, 1952, p. 17, Rockoff (1984)). Additionally, modern data sources are available for the Korean War but are less available for World War II.

[13]We have also studied a set of simulations for a path of government spending that raises demand in sector 1 and lowers it in sector 2 by the same amount. This pure sectoral shift in demand creates what looks like a typical recession; aggregate output, hours, consumption, and real wages fall, while interest rates rise. These effects occur because the capital needed to produce the incremental output in sector 1 is stuck in sector 2.

[14]Early in our research, we also examined the effects of military builddowns, such as the post-Vietnam war period and the period following the collapse of the Soviet Union. These builddowns were much more gradual than the buildups.

[15]In contrast, building the interstate highway system or upgrading health care for the elderly are likely to have significant implications for private technology and consumption.

6.1 *Isolating shocks to defense spending*

To isolate the political events that led to the three large military buildups, we use a narrative approach similar to the one used by Hamilton (1985) for oil shocks and by Romer and Romer (1989) for monetary shocks. We believe this approach gives a clearer indicator of unanticipated shifts in defense spending than the usual VAR approach, since many of the disturbances in the VAR approach are due solely to timing effects on military contracts and do not represent unanticipated changes in military spending. Moreover, unlike the narrative monetary policy dummies, which are in part endogenous (see Shapiro (1994)), these military buildups are unlikely to be the result of feedback from the domestic economy.

Reading narratives around the time of the events also gives us an indication of expectations about future defense spending. We use information from historical accounts, which gives exact dates of events, and *Business Week*, which discusses relevant economic details of the events. We choose the onset dates for each of the three large buildups as follows.

1. **Korean War.** On June 25, 1950 the North Korean army launched a surprise invasion of South Korea, and on June 30, 1950 the U.S. Joint Chiefs of Staff unilaterally directed General MacArthur to commit ground, air, and naval forces. The question then arises as to expectations about the impact of this event on future military expenditures. Readings of *Business Week* give an indication of forecasts of the buildup from the standpoint of businesses. All of the articles clearly implied that the hostilities would lead to a large increase in military spending. Furthermore, *Business Week* noted several times (e.g., July 1, 1950, page 9) that the U.S. was "no longer in peacetime," even if the Communists backed down in Korea. It was generally believed that the U.S. had to build up its military to be ready for any other Communist incursions around the world.

   In the first half of 1950, defense spending was only 6.5 percent of GDP. After hostilities broke out, spending increased steadily and hit peaks of 15 percent of GDP in 1952 and 1953. After the signing of the armistice agreement in July 1953, military spending decreased somewhat but was still 14 percent of GDP in the first quarter of 1954 and 11 percent two years later in 1956. Thus, defense spending stayed much higher than it had been before the Korean War.

2. **The Vietnam War.** It is more difficult to isolate a date for the hostilities leading to the Vietnam War buildup. A military coup overthrew Diem on Nov. 1, 1963, but the United States was still talking about defense cuts for the next year (*Business Week*, Nov. 2, 1963, p. 38;

July 11, 1964, p. 86). The Gulf of Tonkin incident occurred on August 2, 1964, but there was little indication that it would lead to an increase in defense spending. After the February 7, 1965 attack on the U.S. Army barracks, though, *Business Week* began forecasting the anticipated increases in defense spending (March 6, 1965, p. 41, and April 3, 1965, p. 29). Thus, we take the February attack on the army barracks as the key hostility.

Immediately before the shock, defense spending accounted for 8.9 percent of GDP. This fraction fell slightly for several quarters after the shock and then rose until it hit 10 percent in the third quarter of 1967. It was still 10 percent in the third quarter of 1968, but then fell to 9 percent by the first quarter of 1970.

3. **The Carter-Reagan buildup.** The Soviet invasion of Afghanistan on December 24, 1979 seems to have led to a very sudden change in the U.S. policy. The United States was particularly worried about this event because of possible future actions against Persian Gulf oil states. The January 21, 1980 *Business Week* (p. 78) article entitled "A New Cold War Economy" discussed the dramatic suddenness of the change in the outlook for the United States and the expected step-up in defense spending. The article indicated the expectation of a prolonged increase in defense spending.

   When the Soviets invaded Afghanistan, defense spending was under 6 percent of GDP. It rose until it hit a peak (relative to GDP) of 7.7 percent in the third quarter of 1986. By the first quarter of 1997, defense spending was down to 4.3 percent of GDP.

Based on these events, we construct a *military buildup dates* variable that takes the value of unity in the following quarters: 1950:3, 1965:1, and 1980:1.[16] The dummy variable for military buildups corresponds to the big upswings in military spending during the last fifty years. Figure 5 shows the log of real defense spending and defense spending as a percent of GDP. (The real share has declined faster than the nominal share because the relative price of defense has risen.) Our three dates correspond quite closely to the beginning of the three big upswings in defense spending since World War II. In log levels, the 1980s buildup was as great as the Korean War. Relative to

[16]Note that for both the Korean War and the Carter-Reagan buildup, we assign the date to the quarter following the shock because the shock occurred in the last few days of the previous quarter. (In an early version of this paper, we had assigned the two dates to the quarters in which they occurred. We found that some of the results were affected by the burst in consumption in the second quarter of 1950 that was unrelated to the military shock.)

GDP, however, each successive run-up in military spending became smaller as a fraction of the economy. In the bottom panel of Figure 5, the 1980s buildup looks rather small.

6.2 *Econometric specification*

In our empirical analysis, we estimate the reduced-form effect of a military shock on key macroeconomic variables. To estimate the effect of a buildup on a variable, we estimate a univariate autoregressive model where current and lagged values of the military buildup dummy are included as exogenous regressors. The econometric analysis is greatly simplified by the strict exogeneity of the dummy variables for military buildups. Specifically, because there is no feedback to military buildups from the endogenous variable or from other endogenous variables in the economy, this specification will consistently estimate the total effect of military spending on the endogenous variable in question.

The estimates we present in this section are of general interest. They document how the economy responds to an exogenous, unpredictable, and sustained increase in government purchases. They also are useful for examining some of the predictions of our model. Our choice of variables to examine is motivated in part by the variables discussed in the theoretical section. Nonetheless, this empirical section is not precisely a test of the theoretical model, which is highly stylized and has predictions that depend on the details of the model (the form of the production function, for example). The theoretical framework, however, does have some robust implications, which we will highlight in the discussion of the empirical results.

In his discussion of his paper, Martin Eichenbaum presents estimates of the effect of our military buildup dummy by including it in a vector autoregression. Such an analysis could supply further insight into the effects of military shocks. For example, it might show how the effect on GDP of a military buildup is a combination of the real effects highlighted in our analysis and an accommodative (or countercyclical) monetary policy. While our procedure should estimate the total impact of these two channels, it does not disentangle them.[17] Not surprisingly, the impact multipliers of the multivariate estimates are similar to our univariate estimates.

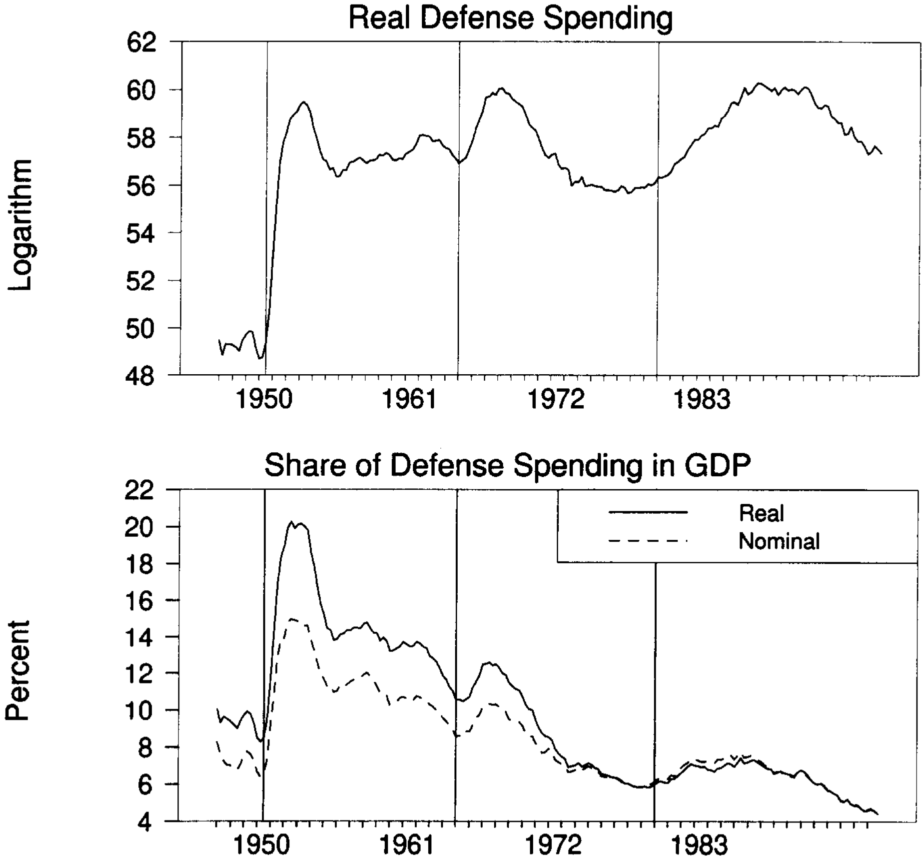
Our estimating equation is

$$y_t = \alpha_0 + \alpha_1 t + \alpha_2 (t \geq 1973{:}2) + \sum_{i=1}^{8} b_i y_{t-i} + \sum_{i=0}^{8} c_i D_{t-i} + \epsilon_t. \qquad (9)$$

The endogenous variable is denoted y_t, the dummy for military buildup is denoted D_t, and the disturbance is ϵ_t. Except for the interest rate, all of the

[17] A VAR would have to be identified in order to separate these effects.

Figure 5. Defense Spending and Military Buildups



Note: Vertical lines are the dummies for military buildups. Real defense spending and real GDP are measured using the chain-weighted quantities.

endogenous variables are in logarithms. To nest both the hypothesis of unit roots and deterministic trends for all of our variables of interest, we estimate our equations in log levels and include a Perron (1987) type of time trend, which means that we include a time trend starting in 1947 (t) and another that starts in the second quarter of 1973 ($t \geq$ 1973:2). The parameters a, b, and c are coefficients to be estimated.

All of the estimates, unless otherwise specified, are based on quarterly data from 1947:1 to 1996:4 (including data for lags). Data are revised as for the May 1997 benchmark revisions of the GDP accounts. The BLS sectoral productivity data, revised in June 1997, also take into account these benchmark revisions. The manufacturing productivity data are available beginning in 1949:1.

To obtain estimates of the impact of a military shock, we estimate the regression described above for each of our variables. We then simulate the impact of the military shock variable taking the value of unity. Thus, our simulations give the impact of an "average" large military shock, where the average is taken over the Korean War, the Vietnam War, and the Carter-Reagan buildup. We report bootstrap confidence intervals for these impulse response functions using Kilian's (1998) bootstrap-within-bootstrap procedure. See the Appendix for a description of this procedure.

Before turning to the estimated impact of the military buildup on the variables of interest, we address the reasonable concern about the explanatory power of a dummy variable that takes a nonzero value in only three periods. Our military buildup dummy has considerable explanatory power. In a regression of real GDP growth on eight lagged values of log level of real GDP (and time trends), adding the current and eight lagged values of the dummy variable raises the R-squared from 0.218 to 0.321. The p-value for the F-test of the joint significance of the buildup dates variables is 0.003.

Table 4 compares the explanatory power of our military buildup dummy to that of defense spending and to the Romer dates for monetary policy contractions and the Hamilton dates for oil shocks.[18] The first line gives the R-squared for a regression of log real GDP on the buildup dummies, the Romer dummies, and the oil dummies.[19] The second line shows that when the log of real defense spending replaces our buildup dummies, the R-squared actually falls by about six percentage points. The third row shows that when the buildup dates are excluded, the explanatory power of the regression falls by 10 percentage points. This fall in explanatory power is less than the fall

[18]The oil shocks are based on dates identified by Hamilton (1985) and Hoover and Perez (1994) and updated by us for the Iraqi invasion of Kuwait. They are 1947:4, 1953:2, 1957:1, 1969:1, 1970:4, 1974:1, 1979:3, 1981:1 and 1990:3.

[19]The regression has the same lag structure and time dummies as the estimating equation introduced above.

in the R-squared when the oil dates are excluded, but greater than when the Romer dates are excluded. Thus, our buildup dates variable has a substantial amount of explanatory power. This result suggests that our dummy variable should be a useful instrumental variable in a wide range of settings requiring autonomous shifts in output.

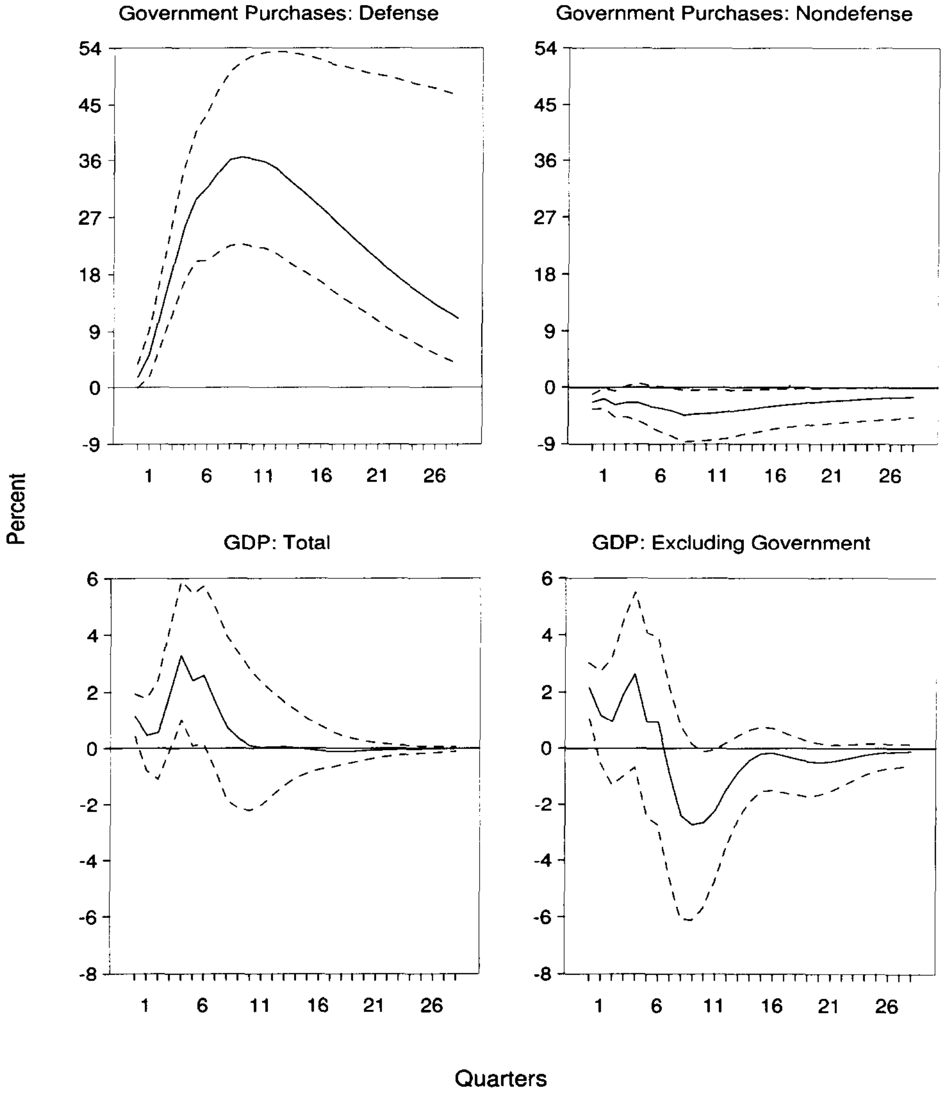
Table 4:
Explanatory Power for Real GDP Growth

Variables included (in addition to 8 lags of log real GDP and time trends)	R-squared	F(9, 155) statistic for current and 8 lags of excluded variable (p-value in parentheses).
Military buildup dates, oil dates, Romer dates	0.539	
Log of real defense spending, oil dates, Romer dates	0.480	
Oil dates, Romer dates (military buildup dates excluded)	0.437	3.8 (0.0002)
Military buildup dates, Romer dates (oil dates excluded)	0.393	5.4 (0.0000)
Military buildup dates, oil dates (Romer dates excluded)	0.488	1.9 (0.0592)

6.3 *Estimated response to military buildups*

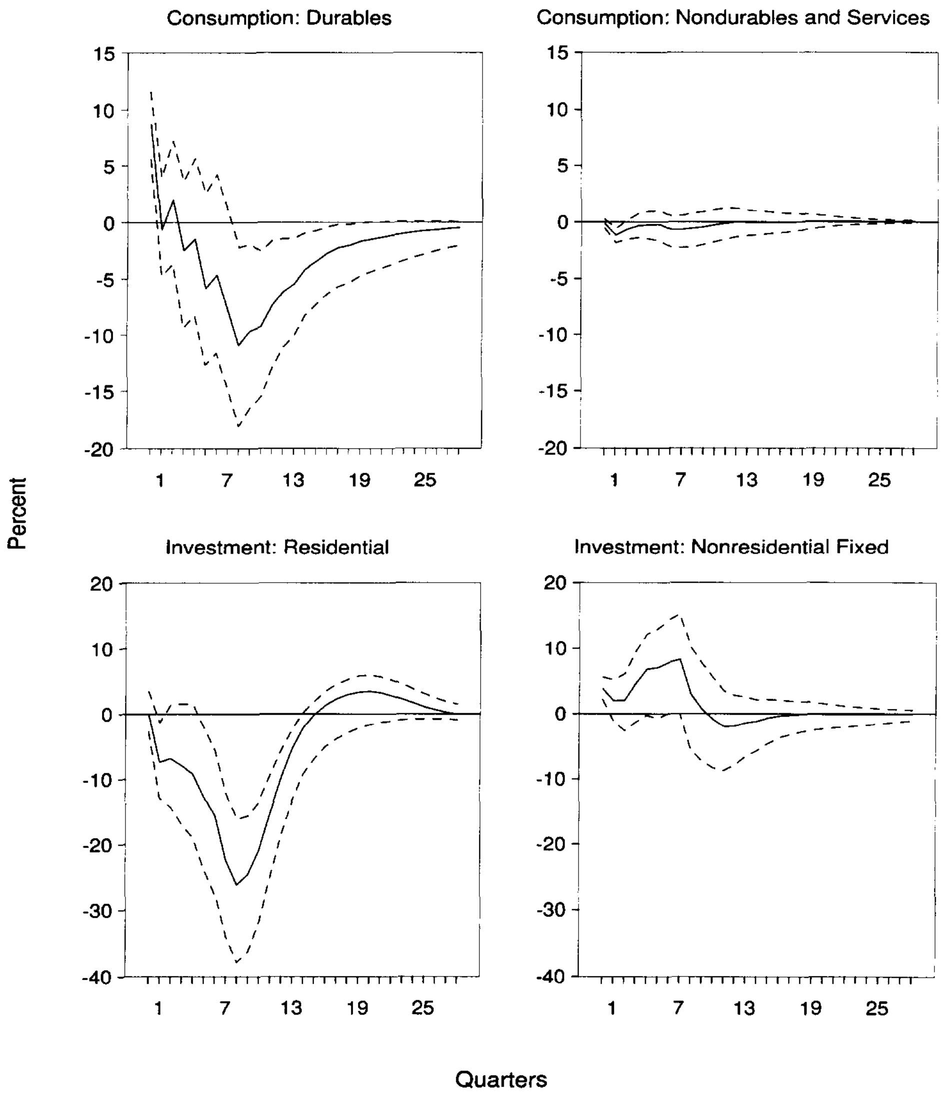
In this section we present the estimated impact of a military buildup on a variety of variables using the econometric estimates discussed in the previous section. Figures 6A through 6E show the dynamic response of key macroeconomic variables to a military shock. In several graphs, we compare the behavior of variables in private business to those in total manufacturing. While durable-good manufacturing better fits the sectoral detail discussed earlier, we use total manufacturing for comparison with other papers in the literature. The results using durable-good manufacturing are similar in most cases.

Figure 6A. Estimated Response to a Military Buildup



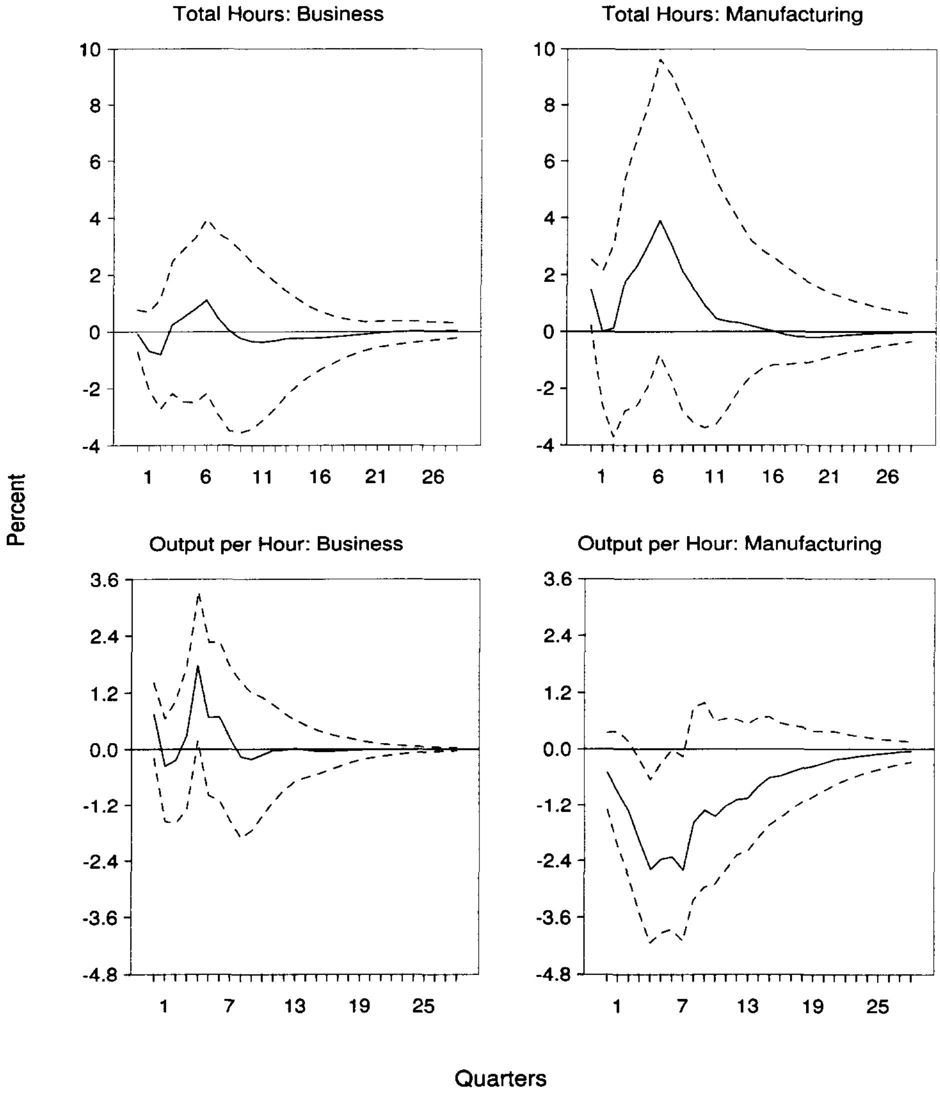
Note: Solid lines are the estimated impulse response to a dummy variable that is equal to one with the onset of a military buildup. Dashed lines are the 10 and 90 percent bootstrap-within-bootstrap confidence bands. See text for details of the estimation procedure.

Figure 6B. Estimated Response to a Military Buildup



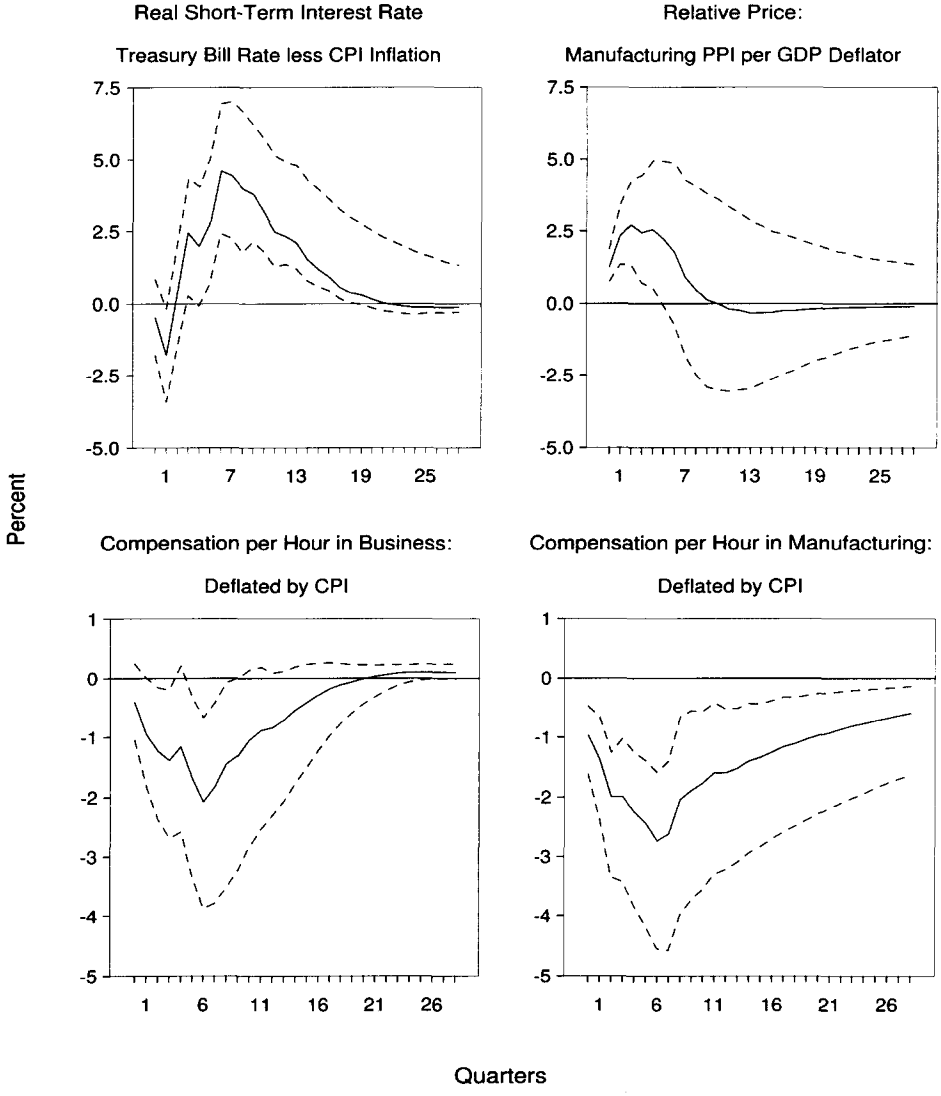
Note: Solid lines are the estimated impulse response to a dummy variable that is equal to one with the onset of a military buildup. Dashed lines are the 10 and 90 percent bootstrap-within-bootstrap confidence bands. See text for details of the estimation procedure.

Figure 6C. Estimated Response to a Military Buildup



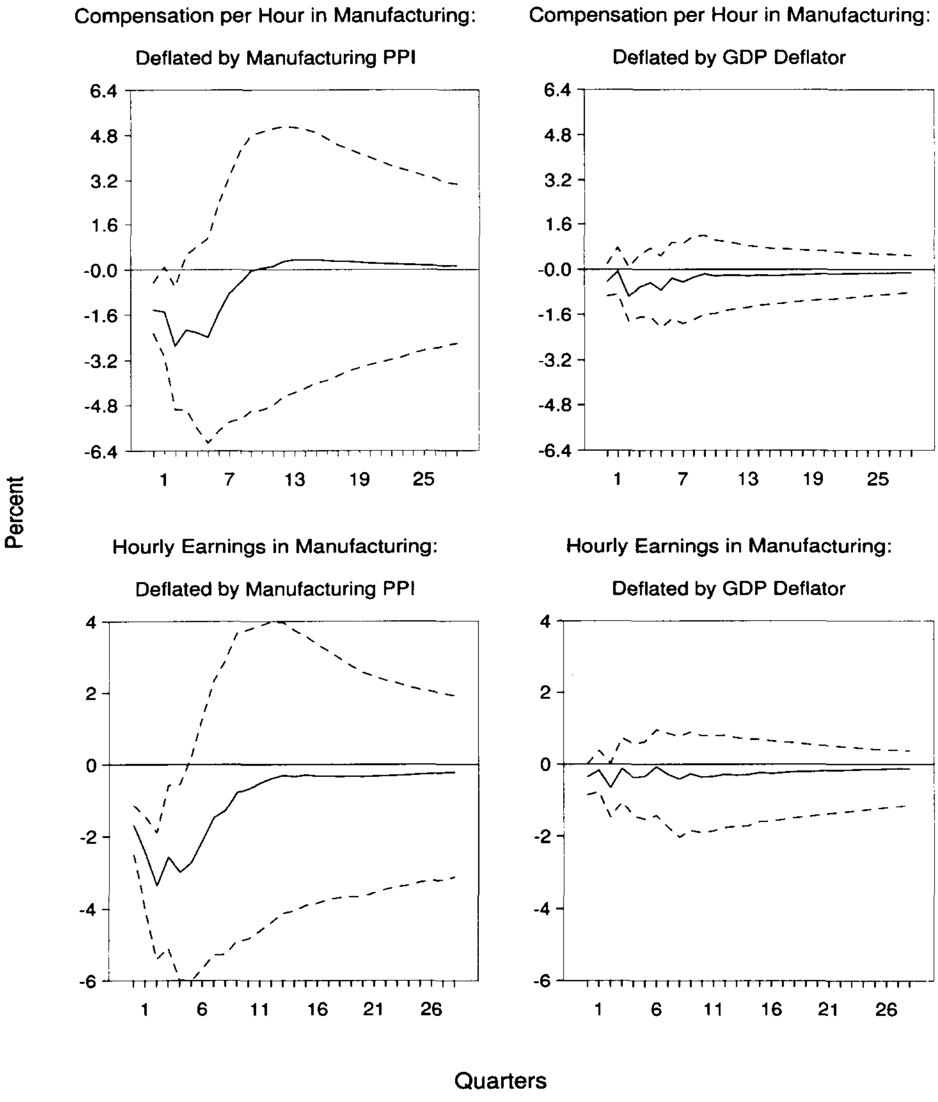
Note: Solid lines are the estimated impulse response to a dummy variable that is equal to one with the onset of a military buildup. Dashed lines are the 10 and 90 percent bootstrap-within-bootstrap confidence bands. See text for details of the estimation procedure.

Figure 6D. Estimated Response to a Military Buildup



Note: Solid lines are the estimated impulse response to a dummy variable that is equal to one with the onset of a military buildup. Dashed lines are the 10 and 90 percent bootstrap-within-bootstrap confidence bands. See text for details of the estimation procedure.

Figure 6E. Estimated Response to a Military Buildup



Note: Solid lines are the estimated impulse response to a dummy variable that is equal to one with the onset of a military buildup. Dashed lines are the 10 and 90 percent bootstrap-within-bootstrap confidence bands. See text for details of the estimation procedure.

The top two panels of Figure 6A examine the effect of a military buildup on government spending. The first panel summarizes the effect of a buildup on real defense purchases. The next panel shows the response of nondefense purchases.[20] A military buildup leads to a sustained and dramatic increase in defense purchases. Expenditures increase sharply; they peak after two and one-half years at 36 percent above trend. The dashed lines show the 10- and 90-percent confidence intervals. (See the Appendix for details of computation.) The confidence interval is small in the early quarters, then widens substantially and becomes asymmetrical. Nondefense purchases experience a sustained and substantial fall following a buildup. The peak decline is four percent from trend. Hence, the military buildup has the compositional effects we discuss in the theoretical section.

The second pair of graphs in Figure 6A shows the impact of the military shock on the log of GDP and the log of private GDP (defined as GDP less total government purchases). Both total GDP and private GDP increase in response to a military shock in the first few quarters. While total GDP remains positive for three years, private GDP becomes negative after two years. Qualitatively, these results are not out of line with the predictions of the models presented in the first part of the paper. Recall that private GDP rose for a year in the simulations before turning negative. The increase in GDP is statistically significant from zero at the ten-percent level only on impact and then at horizons of about a year.

The first pair of graphs in Figure 6B shows the behavior of durable consumption purchases and the sum of nondurable and service consumption. Immediately after the military shock, durable-goods purchases rise substantially, but then turn significantly negative. Most, but not all, of the initial rise can be explained by the panic buying after the start of the Korean War, although even with the Korean War excluded there is a small spike-up in the first quarter. In contrast, nondurable and service consumption show a statistically significant fall after the shock. They are down 1.2 percent in the first quarter after the shock, and then slowly return to trend. This is a fairly large response on its own scale, but is small relative to the decline of spending on durables. Except for the first quarter after the shock, the confidence bands include zero. The bottom left panel of Figure 6B shows the response of residential investment. Though housing is classified as investment in the national accounts, in this context it should be thought of as a component of durable consumer spending. Residential investment falls substantially and statistically significantly. At its trough after nine quarters, it is 26 percent below trend. It remains below trend for another several years.

Except for the initial behavior of durable-goods purchases, the behavior

[20]All real national accounts data are measured using the chain-weighted quantity indexes.

of consumption is consistent with the negative wealth effect that is at the heart of the neoclassical explanation for the effects of government spending. Nondurable and service consumption falls modestly. Durable and housing expenditure falls significantly with little or no subsequent rebound. Hence, their stocks have long-lived reductions as a result of the military buildups with the consequent sustained decline in consumption flows.

The difference in patterns between nonresidential investment and residential investment in the bottom panels of Figure 6B is striking. Nonresidential investment rises significantly after the military shock. Again, there is only a small and statistically insignificant subsequent decline in investment. Hence, the military buildup leads to a sustained increase in the stock of productive capital. This shift in the composition of wealth toward productive capital and from consumer durables and housing accords with the predictions of the theoretical analysis.

We next examine the effect of military buildups on hours and productivity. The top pair of graphs in Figure 6C shows the effect of a military buildup on hours in all of private business and in manufacturing.[21] Hours in all of private business peak at 1.1 percent, but the estimate is not significantly different from zero. Hours in manufacturing rise proportionally more, rising 3.9 percent at the peak in quarter seven, but again the response is estimated imprecisely. The point estimates that hours increase is consistent with the model's predictions, although most alternative models would also predict an increase in hours.

The bottom panels of Figure 6C show the response of labor productivity to a military buildup. In total business, output per hour and hours move in the same direction. This finding is not consistent with a neoclassical model, although the estimates are quite imprecise. On the other hand, output per hour in manufacturing falls significantly. Its confidence interval is mostly in the negative part of the half-plane, and the point estimates are significantly negative at horizons centered on 5 quarters. This countercyclical labor productivity is what a neoclassical model would predict and matches the predictions of our Cobb-Douglas model.[22] These results for the average product of labor are not inconsistent with results in the literature on the correlation between government spending and the Solow residual. While Hall (1988, 1990) and Evans (1992) show that government spending and the Solow residual are positively correlated at the aggregate level, Hall's disaggregated industry results show that rarely is the correlation significant at the industry level.

Our remaining empirical results concern the behavior of factor and out-

[21]These estimates are for the 1949:1 through 1996:4 sample period (including data for lags). The data are the BLS sectoral productivity indexes and are revised as of June 1997.

[22]Recall that in the Leontief model, productivity is fixed by assumption.

put prices. The first panel of Figure 6D shows the response of the short-term real interest rate to the military buildup.[23] The real interest rate falls significantly, then slowly rises, and finally returns to its baseline. This time path accords surprisingly well with that for nondurable and service consumption in Figure 6B. The level of consumption falls first and then slowly increases. The derivative of this path matches the path of real interest rates. The response of the real interest rate to the military buildup also corresponds to our theoretical simulation. In the standard frictionless model, the interest rate should strictly rise. Our model with costly adjustment predicts a temporary decline in the real rate (see Section 5.2 and Figure 3B) owing to the ex post excess supply of the consumption good.

The next panel of Figure 6D shows the price of manufacturing relative to the general price level as measured by the GDP deflator. The military buildup causes the price of manufacturing output to be bid up, as our model predicts. Interestingly, the return of relative prices to steady state occurs relatively quickly. Prices are back to their steady-state value at the peak of the buildup (in terms of expenditure).

We now turn to the response of the real wage to a military buildup. Because the response of the real wage to government spending has received a large amount of attention in the literature – often with different measures – we examine the response of a number of different series. The bottom panels show the compensation per hour in business and manufacturing deflated by the CPI.[24] In both total private business and manufacturing, real compensation per hour declines in response to a military buildup. The peak response in business is a decline of about two percent; the peak response in manufacturing is somewhat higher. The equalization of consumption wages across sectors is consistent with frictionless mobility of labor. The overall decline in wages is consistent with a neoclassical response to a military buildup: The negative wealth effect causes labor supply to increase. More labor effort with a fixed technology leads the wage to decline. As the capital stock adjusts, the wage reverts to its baseline.

Figure 6E gives alternative measures of the wage in manufacturing. The top two panels deflate compensation per hour by the manufacturing PPI and the GDP deflator. The bottom two panels examine the same deflators, but use average hourly earnings as the numerator.[25] The PPI-deflated measures

[23]Real interest rates are measured as the three-month Treasury bill rate minus inflation (annualized growth in the CPI over the next quarter). The results in the figure are based on the response of the ex post real rate. Results based on separately estimating the effect on the nominal interest rate and on inflation and taking their difference are similar.

[24]The compensation per hour series is from the BLS productivity series. The sample period for both business and manufacturing is 1949:1 through 1996:4 including data for lags.

[25]The sample period for the results with compensation is 1949:1 through 1996:4. For

of labor cost are meant to correspond to the product wage. For comparability with Rotemberg and Woodford (1992), we also deflated the wage using the implicit price deflator for GDP. Whether measured by earnings or compensation, the product wage in manufacturing falls with the military buildup. This finding accords with the neoclassical model.

In contrast, using the deflator for GDP, the real wage in manufacturing falls, but only slightly, and not statistically significantly. Rotemberg and Woodford report an increase in a similar measure of the wage in response to a government-spending shock, and use this result to argue against models with stable labor-demand curves. In the April 1997 Conference draft of our paper, which used data that spliced the unrevised pre-1959 data to the post-1959 chain-weighted data, we also reported a slight increase in the GDP-deflated manufacturing wage in response to our military dummy. When we deflate by the newly revised implicit GDP deflator (the ratio of nominal GDP to chain-weighted real GDP), we obtain the results reported in Figure 6E.

Although the new data no longer show an increase in the GDP price-deflated manufacturing wage in response to a military buildup, the stark contrast with the product wage is still clear. Christiano (1990), in his discussion of the Rotemberg and Woodford paper, noted that their wage results were not robust to changes in data definition. Our sectoral analysis can explain this finding. When defense purchases are sector specific, and when capital is not perfectly mobile across sectors, prices and average wages behave differently across sectors.

With the newly-revised data, there is no evidence for an increase in the real wage after a military buildup. Moreover, the product wage, which is the correct argument in the labor-demand function, moves consistently with a wealth-induced shift in labor supply moving along a stable labor-demand curve.

7 Conclusions

Accounting for the compositional effects of government spending is important for understanding the aggregate effects of changes in government spending. We demonstrate that changes in government sending are often very sector-specific. This fact becomes critical in an economy with costly mobility of capital. Using a two-sector model with costly mobility of capital, we show that this friction can significantly change the aggregate effects of government spending. In particular, the effects on output and hours may be magnified, interest rates may fall, and real consumption wages may rise. The model

hourly earnings, it begins in 1947:1. Results for hourly earnings using samples beginning in 1949:1 are similar.

also demonstrates the importance of preserving the distinction between the product wage and the consumption wage when studying the effects of shocks to demand that affect the sectoral composition of output.

The empirical results in the last part of the paper document the stylized facts of the response of the economy to a large military buildup. We show that virtually all of the series exhibit behavior that is consistent with our two-sector neoclassical model. In particular, we find that product and consumption wages fall following a military buildup. GDP price-deflated wages, though they fall according to the point estimates, are much flatter and do not change significantly from zero. This finding runs counter to other evidence reported in the literature.

While our empirical results are consistent with the neoclassical framework, they are also potentially consistent with other models. The empirical evidence showing the negative comovement of real product wages and hours is consistent with any model in which an increase in government spending moves the economy along a given labor-demand curve. For example, Keynesian models in which workers are either fooled into supplying more labor or are involved in contracts where firms have the right to call up additional labor at a fixed nominal wage can also explain the observed behavior of wages and hours.

Finally, this paper illustrates the potential explanatory power of multisector models with costly capital mobility, particularly with our assumptions on technology and variable workweeks. Our model allows for perfect mobility of labor, yet produces results that are similar to alternative models with imperfections in the labor market. For example, sectoral shifts can lead to declines in employment and variations in the wages paid across sectors. It is likely that consideration of the sectoral structure of the economy can explain other aspects of the data as well.

Appendix

Bootstrap-within-Bootstrap Confidence Intervals

To estimate the confidence intervals, we have adapted Kilian's (1998) bootstrap-within-bootstrap. The point estimates (solid lines in Figure 6) are the estimated ordinary least squares impulse response functions. The bootstrap-within-bootstrap estimates of the confidence intervals are constructed in two major steps. First, the first-order bias of the OLS estimates is computed using the bootstrap. Second, the bootstrap estimate of the confidence interval is estimated by drawing bootstrap replications based on the bias-corrected estimates, again bias-correcting these estimates, and then tabulating the impulse response function. Figure 6 reports the 10 and 90 percentile of the bootstrap distribution of the impulse response functions.

The results are based on 250 replications to compute the first-order bias and 2500 replications of the impulse response function. If the bias-corrected estimates were explosive, we did not use them in the second stage. Instead, we shrank the bias-corrected estimates so that the largest autoregressive root was one-half the distance between the OLS estimate and the unit circle. In the second stage, if the replication prior to bias correction was explosive, we used the OLS estimate to compute the impulse response function. If it was explosive after bias correction, we shrank the coefficients using the same procedure as in the first stage.[26]

For the lagged value to startup the bootstrap replications, we randomly sampled blocks of the data of length equal to the number of lags.

[26]Kilian uses a different procedure to shrink explosive estimates, but applies it in the same situation as described here.

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