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The Pennsylvania State University
The Graduate School
Department of Economics

Government Spending, Research and Development, and Growth

A Master's Paper
in
Economics
by
Mark H. Brownell

Submitted in Partial Fulfillment
of the Requirements for the
Master of Arts Degree

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Table of Contents

Accesion For
NTIS CRA&I ☒
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Justification
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Distribution /
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A-1

I. Introduction

Over the last thirty years the US government has been the largest monetary contributor to the research and development process. But is this money wasted? Is government financing of research and development a key ingredient in the recipe for growth? In an effort to answer this question, I will apply economic growth theory to government research and development policy. Specifically, I will look at military R&D efforts. The government funding of research and development (R&D) via the military is a very controversial issue. Opinions are varied over everything from the specificity and usefulness of military products to the numerous regulations governing the free flow of "top secret" information. As a result, military R&D is subject to vast scrutiny and many constraints. By examining the government funding of military R&D and its effects on growth, I hope to draw generalizations that will apply to any type of government funded R&D. I will use information on growth theory to provide a background for this analysis.

In theory, technological change is the driving force behind economic growth; however, the relationship between individuals' actions and the growth rate is undefined. Two factors which are often consider key to the growth process are R&D and human capital. Economist Albert Link defines research as "the primary search for technical or scientific advancements," and development as "the translation of these advancements into product or process innovations."[1] Human Capital is "the bundle of skills an individual possesses" and is often measured as the level of an individual's education.[2] Although

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[1] Link, Albert N., <u>R&D Activity in US Manufacturing</u>, New York: Praeger, 1981, p3.
[2] Schiller, Bradley R., <u>The Economy Today</u>, 2ed., New York, 1983, p851.

these two factors seem to be the main ingredients for growth, economists argue over the recipe which tells us how each ingredient specifically affects growth. I will concentrate my discussion of the growth recipe to the R&D component. Specifically, my goal is twofold. First, I hope to discover the theoretical policy implications of government funded research and development. Second, I want to see if the theory agrees with reality.

To accomplish these goals, I must look at each ingredient of the growth recipe individually. I will start with a brief presentation of the key findings of studies on economic growth. In this section, I will also present the criteria necessary for a new model of growth to be successful. Then, in the third and fourth sections, I will apply this criteria to the current controversy over the government funding of research and development through the military. By looking at the arguments for and against military R&D as well as the current issues, I will draw some policy implications that should apply to all types of government R&D funding. This will conclude the background portion of my paper. In section five, I will depict a theoretical growth model that accounts for government spending on both military and non-military ventures. From this model, I will draw conclusions about the optimal size of the government. Furthermore, this model will provide a framework for the empirical analysis in section six. Section six will have two major parts. First, I estimate the theoretical production function. Then, once it is validated, I will estimate the rate of technological change and see what effects, if any, government R&D has on it. Finally, I will present my overall conclusions and policy recommendations.

II. Growth Theory Background

For many years, the dominant model of growth included little about research and development or human capital. In 1956, Robert Solow created a model that we now know the neoclassical growth model. Solow's ideas dominated growth theory for the next few decades. His model maps economic growth as a function of exogenous technological change. He concentrates on capital formation which he finds is related to the savings rate. In his model he hypothesizes that in an economy with a low capital to labor ratio, capital will have high returns. Furthermore, since savings provides money for investment in capital, capital investment will continue occur until the returns to capital are only able to offset the effects of depreciation. Then, the economy will be stuck in a steady state with a constant standard of living. He notes that standard of living could increase with sustained technological growth, but does not explain how technological growth occurs.

Unlike the Solow approach, the recent trend in growth theory has been to try and explain how technology grows as a function of economic inputs such as human capital and research and development. This new trend has been given the name of endogenous growth theory. Economists Gene Grossman and Elhanan Helpman present a survey of endogenous growth models in the Journal of Economic Perspectives (winter 1994). Their article presents two fundamental insights which are relevant to this paper. First, they summarize the work of Joseph Schumpeter who claims that the amount of innovation increases as the expectation of earning future profits increases. Second, Grossman and Helpman also relate the findings of their recent paper (1991). When modeling innovation growth, they found a long-term sustained growth pattern in knowledge (which may seem obvious, but is now economically proven). Furthermore, they found that increases in the profitability of R&D will increase both R&D and the rate of economic growth (backing Schumpeter's claim). Likewise, they found that innovation in the innovative process (i.e. innovations that make it easier to invent) will also increase R&D and, therefore, growth. Incorporating these findings into a new model is crucial, for no new model can fully explain growth without including these relationships.

Similar to the findings cited by Grossman and Helpman, endogenous growth economist Paul Romer (1994) sights the five facts that he believes a new comprehensive macroeconomics model will need to include in order to accurately explain growth:

1) Many firms exist in a market economy. This fact ,while seemingly obvious, tells us that the economy is not dominated by a single firm.

2) Technological discoveries, unlike other inputs, may be used by many people simultaneously. Fact two describes the public good aspect of discoveries. More specifically that information is non-rival in consumption.

3) Physical activities are replicable. Fact three deals with returns to scale of economic inputs. In a constant returns to scale environment only physical activities need to be duplicated in order to double output. This implies that non-rival inputs (information) do not have to be doubled in order to double output. Moreover, if physical activities can be repeated, then all new information can be used simultaneously as suggested in fact two. Therefore, economic growth can continue to occur as long as technological growth continues.

4) People create technological advance. Fact four is the basic assumption of endogenous growth; people's actions and inputs create technological advance. In other words, investment in human capital and research and development cause growth. Solow's neoclassical model recognizes this fact but cannot account for it.

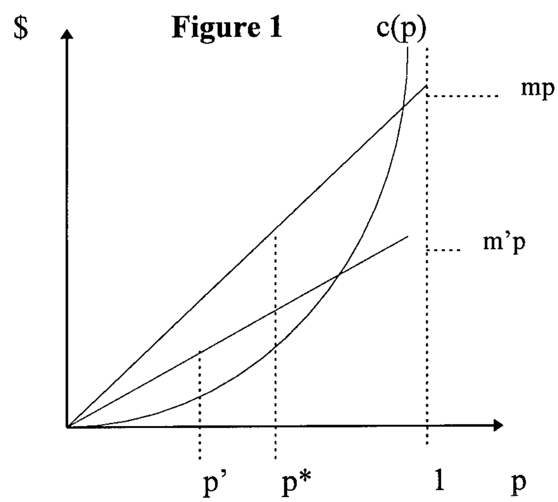
5) Many individuals and firms have market power and earn monopoly rents on discoveries. Fact five describes the incentives necessary for people to invest in discoveries. In other words, the guarantee of market power and monopoly profits is a large reason people invest in research and development. This is in agreement with what Schumpeter and Grossman and Helpman found.

In these five facts Romer lays the foundation for further work in endogenous growth. I will call these facts the "Romer criteria." Including the Romer criteria in a new model means creating a tradeoff between facts 2 and 5. Technological information (discovery) is a partially public good because it is non-rival in consumption and only partially excludable. Therefore, the major problem is to balance the tradeoff between maximizing growth and providing incentives for discovery. Ideally, to maximize growth technological information should be shared and productively used by all firms. This is a classic example of a positive externality. The positive effects of technology can affect everyone not just the firm that creates it. Generally, a firm will only make decisions based on its own marginal costs and benefits. The firm will not take into account the effect that technology has on society. As a result, less R&D and hence less technology is produced than is socially optimal. In other words, if a firm does not reap the full benefits of its R&D efforts, it will under allocate resources to R&D. Therefore, because it is a competitive market the only way firms will invest resources in the discovery of this information is to be insured of future profits (in order to offset the cost of discovery). Consider the following example. Let p be the probability of inventing a new technology. Let c(p) be the cost of attaining a higher probability where c' > 0 and c'' >> 0 (i.e. no amount of money will ensure innovation at probability 1). Then, the profit a firm makes is a function of its monopoly rents and the cost of invention. This relationship can be generalized to:

profit = mp - c(p)   where m is the constant amount of monopoly rent.

Graphically, this relationship takes the following form:

Figure 1



The graph shows that if monopoly rents exist, then the amount of innovation (or probability of invention) will be p*. Likewise, if monopoly rents are removed (profit m'), firms will have less incentive to invest in innovation. Consequently, the amount of innovation will decrease to p'. The problem for growth economists is to provide incentives to the firms and at the same time promote simultaneous use of technology. I will concentrate on this tradeoff while exploring the issues of government provision of R&D.

III. Military R&D Background

Understanding the Romer criteria now allows me to examine the controversy of government funding of research and development. Should the government fund technological growth via investments in R&D and human capital? Or should it be left completely in the hands of the free market? Economist Albert Link (1981) makes a case for the public provision of R&D funds. He feels that not only is information a public good (and under produced), but also that R&D involves large amounts of risk; therefore, no amount of money can guarantee successful innovation. Thus, the government should step in and provide funding. This should increase economies of scale and profits as well as development of human capital.[3] On the other hand, many congressmen and constituents alike argue that the government should let the "invisible hand" do its job.

In recent economic literature, many people have examined the issue of government spending on growth. The consensus of these works is that government has at best a negative impact on growth. However, this is a controversial result and is subject to further study. Likewise, the issue has never been fully dissected in the manner that I am attempting. I would like to examine the impact of not only government spending on growth, but I would also like to determine if their is a significant difference between R&D efforts via for the military and other types of R&D ventures (non-military

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[3] Link, p.80.

government, academic, and company funded). This "difference" is currently being debated in Congress-- specifically over the budget for military R&D funding. Advocates of defense spending argue the military spending creates "spin-off" technologies that are monumental in the growth of the US economy. On the other hand, rivals of defense spending argue that military outlays for research and development only detract from the growth rate by stealing resources and using them inefficiently. In this section, I will look at both sides of this issue in greater detail. In doing so I hope to see if military R&D is significantly different from other types of R&D. I will begin with the arguments against military (government) funded R&D efforts.

A. A Case Against Military R&D: Depletion Theory

The main opponents to military R&D spending believe in "depletion" theory. Depletion theorists, argue that investment in plants and equipment and spending on R&D are the prime determinants of growth. Additionally, they believe that the defense sector depletes the nation's level of human capital and resources. They contest that the defense sector "hogs" the stock of scientists and engineers, thereby causing civilian firms not only to have a shortage of skilled labor, but also prevents these firms from practicing cost minimizing production. This, in turn, will lead to inefficiencies in commercial markets.[4] If firms cannot produce at cost minimizing levels, they will attempt to pass the higher costs onto consumers. This will force markets out of equilibrium and lead to

[4] Adams, Gordon and David Gold. "Defense Spending and the Economy: Does the Defense Dollar Make a Difference?" Defense Budget Project, Wash. D.C. 1987, p13-14.

inefficiencies in the whole economy. This argument is an extension of the crowding out effect. However, instead of government debt crowding out private investment, depletion theorists believe that government R&D is crowding out private sector R&D. This argument is backed up by a study done by Robert Lucas (1988) which concluded that people with higher levels of human capital tend to migrate from where human capital is scarce to where it is abundant.[5] This contradicts economic intuition. Theoretically, human capital should flow from where it has a low marginal product (places of abundance) to where it has a relatively higher marginal product (places where it is scarce). This type of transfer should occur until marginal products are equalized. If Lucas is correct, quite the opposite is happening, and great disparity in concentrations of human capital are created. This could possibly be due to the increasing returns to scale for human capital (i.e. it is more efficient for scientists and engineers to work together). But, for the depletion theorist, this means that the defense sector will continue to gain human capital and civilian sectors will continue to be depleted. Therefore, the problem is self-perpetuating, and the eventual consequences to the US economy will be catastrophic.

The second problem stems not from the depletion of human capital, but from the depletion of resources. The resource depletion effect is best summarized by economist Lawrence Klein:

> "there is an inherent gain in producing goods that are going to go into a civilian capital structure, because they will ultimately produce a future income stream. By contrast, producing military goods whether used for destruction or whether they self-destruct doesn't generate a future income stream."[6]

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[5] Romer, Paul. "The Origins of Endogenous Growth," Journal Of Economic Perspectives. vol 8, winter 1994, p15.

[6] Bartel, Richard. "The Economics Of Turning Swords into Plowshares," (interview of Lawrence Klein) Challenge, March-April 1990, p18.

Klein backs this up with two pieces of information. First, he states that a 5% cutback in military spending is associated with 3% expansion of civilian consumption. Second, he states that real civilian R&D spending is falling in the US, but military R&D is not.[7] Both these points support the arguments of the depletion theorists because they imply that the civilian sectors is, in fact, being depleted (while the defense sector is not).

The problem mentioned by Klein also seems to be self-perpetuating because of government contracting regulations and profit expectations. Romer stated that expected profits and market power gained from discoveries are the main incentives for R&D outlays. Government contracting regulations guarantee that firms will be paid a certain percentage of costs as profit. For example, for items such as naval vessels and planes firms are guaranteed receive 10% of total cost as profit.[8] High profit expectation will cause resources to (over)flow into the defense sector. In turn, the defense sector will experience a drop in marginal returns causing the extra resources to be less productive. Furthermore, this guarantee of profits not only provides incentives for firms to spend money on defense related R&D efforts, but it also provides incentives to perform cost maximizing production rather than cost minimizing production. Depletion theorists argue that defense contractors inflate their costs in order to earn inflated profits. This practice, then, allows defense contractors to draw in even more resources from the civilian sector. In fact, a study by the RAND Corporation found results similar to Lucas' but for the flow of resources (money). RAND found that "over a period of several years, the typical firm

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[7] Ibid., p20.

[8] Weidenbaum, Murray. Small Wars, Big Defense: Paying for the Military After the Cold War, New York: Oxford Press, 1992, p100.

spends an additional dollar of its own funds for [independent] R&D in response to a dollar of increased government support."[9] This study indicates that government R&D acts like a magnet for firms R&D. Therefore, the government has great influence over what technological areas have higher levels of R&D.[10] Specifically, the government can draw "too many" dollars to the defense R&D sector, and, thus, lower the marginal returns to that money (as in the Lucas human capital argument). Therefore, the depletion becomes self-perpetuating.

The bottom line of all these arguments is that military R&D creates inefficiencies in the marketplace by using up scarce resources and human capital without producing a future income stream, and by redistributing scarce resources and human capital to lower marginal returns production sectors. Furthermore, these problems are self- perpetuating. The cumulative long-term impact of trying to advance growth via military R&D hurts more than it helps. In fact, depletion theorists feel that the US would be as economically successful as Japan and Germany had it not been for their high military budget.

B. A Case for Military R&D: Spin-Off's

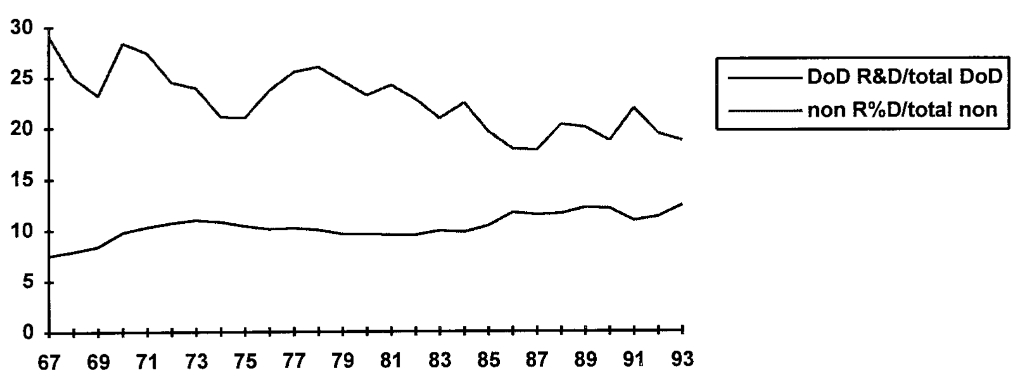
Depletion theorists make a strong case against high military R&D spending, but they do not lend any weight to the benefits of government funded R&D. Benefits from

[9] Ibid., p101.

[10] Other empirical studies testing this proposition are controversial, but studies by Wise and Agnew, Terleckyj, and Goldberg have argued that society does not see the full productivity gains of military R&D. Link give four possible reason for this: 1) firms do not know how to get the technical information from the government, 2) firms do not have the technical expertise to incorporate the information, 3) firms have high costs of installing new high-tech capital, and 4) government regulations prevent free use of information. (although Link does admit that some of the returns to government R&D are hidden in the returns to commercial R&D. The combined effect of R&D is greater due to spin-offs and spin-ons). Link, p80-2.

high levels of military R&D outlays come from two main areas: national security and spin-off technology. Maintaining national security is the basic function of the US military. Outlays for military R&D are essential in keeping the US technologically ahead of the "competition." This issue is especially relevant in today's world. With the defense drawdown, the number of military personnel is shrinking to about half the level of its 1985 high; therefore, technologically advanced weapons are crucial to maintain the same level of military readiness. In fact, as illustrated below, the ratio of federally funded defense R&D to total defense spending has been increasing over time; whereas, the ratio of non-military federally funded R&D to total non-military federal spending has been decreasing over time.

Graph 1



This graph indicates, that Congress recognizes the need for a more technologically advanced force structure. Furthermore, the end of the Cold War has given rise to great uncertainty and instability in the world. Small countries can no longer simply choose a side of the traditionally bilateral conflict. As a result many low intensity conflicts have arisen, and US military forces are busier than ever. Despite the increase in demand for

US forces, Congress has lowered the limit on the total size of military personnel. To compensate for this the military is substituting away from labor to capital. However, Congress sets the limit on capital too, so in order to obtain maximum returns to capital the government needs to fund military R&D efforts. Unfortunately, military readiness and national security are hard to quantify making this argument hard to support other than on theoretical grounds. Fortunately, on the other hand, this point is not central to the issues discussed in this paper. Although the level of military readiness is a key determinant of military R&D outlays, I am looking at the effectiveness of these outlays proportional to their size, not their total size. Therefore, I will concentrate on the second point, spin-off technology (but I will mention national security from time to time).

Spin-off technologies (also known as dual use technologies) are technologies developed for the military but have been adapted for civilian use. Some major spin-off's from over the years include computers, jet airlines, composite materials, and command, control, and communication technology.[11] Advocates of military R&D argue that most spin-off's come from high technology, high risk developments, and most firms cannot bear the costs or risks associated with this type of investing. The Romer criteria suggest that risky R&D is precisely the kind that should be funded. The riskier the investment the more of a public good it becomes. Since no firm can internalize the full benefits of a public good, decision making on investing in high risk R&D is done with full costs in mind, but not with full social benefit in mind. Therefore, the result is under- allocation of resources to R&D. Perhaps this is why the Department of Defense has been the major

[11] Command, control, and communications (otherwise known as C^3) are used for military troop movements and battle field control. They are things such as tracking and surveillance systems.

financier of R&D as well as the largest purchaser and developer of new scientific applications.[12] Since the US government has funded high risk military R&D, it has maintained its advantage in the high-tech capital goods market. In fact, some believe that this advantage was the "fuel of the export boom" of the early 1990's.[13] In any case, the role for government funding of military R&D is to start the "learning curve" as it did with the computer and aerospace industries. By funding these types of high risk, high-tech, and high potential innovations the government's ultimate impact on technological growth can be tremendous.

C. Current Issues

Despite its role in aiding the US high-tech capital market, defense technology is beginning to fall short of its spin-off potential. By implementing strict procurement regulations DoD has erected barriers to the flow of technology. Not just technology leaving the military, but spin-on technology as well.[14] Many, including Director of the Harvard Science Technology and Public Policy Program, Lewis Branscomb, argue that the developments of military R&D are too specialized to be converted effectively to the civilian world. He claims that "Defense R&D tends to be too slow, too centralized and too micromanaged to be transferred successfully to the private sector. Defense researchers tend to be too far removed from commercial markets to have much impact."[15]

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[12] Weidenbaum, p89.

[13] Minnich, Richard T., "Defense Downsizing and Economic Conversion: An Industry Perspective," Downsizing Defense, ed. Ethan Kapstein, Congressional Quarterly, 1993, p.131-2.

[14] Adams, Gordon, Cain, Stephan, and Schmidt, Conrad, "The Defense Budget and the Economy: What the Transition Will Look Like," Defense Budget Project, June 1990, p18.

[15] Weidenbaum, p97.

In other words, only a small percentage of military related innovations are useful in the private sector. In fact, today's downsizing of the defense sector has forced many firms out into the civilian marketplace. Defense industry firms are finding it extremely difficult, if not impossible, to convert over to this new environment. Their main problems are changing from government to civilian regulations and customs, and converting their plants to commercial goods production.

The other side of the coin is the inability to use spin-on technology. The Pentagon does not want to buy off-the-shelf technology for reasons of national security. (Of course some believe it's for reasons of job security.) However, as of late DoD has become a net user of civilian research, because many DoD procurements, such as microchips, are ten times as expensive and two generations behind their civilian counterparts.[16] This is just one example of an industry (computers) which was initially inspired by military R&D, but which has now surpassed its creator in both innovative and productive capability. However, a few recent spin-offs have come close to the "computer" magnitude. One, the Global Positioning System(GPS), appears to have a vast potential that is only slightly tapped. GPS is a satellite tracking and locating program. The military uses it for targeting and troop positioning. The civilian sector is applying it to everything from tracking trucks and shipping to recreational hiking.

Should, then, the goal of military R&D be to produce spin-off's? If the US is interested in growth maximization, the answer is yes. On the theoretical level, the government should actively pursue the development of spin-off (or dual-use technology)

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16 Ibid., p90-3.

because R&D is a public good. This course of action also makes perfect sense in light of the smaller defense budget, for the government would still maintain military readiness and at the same time help create the public good, R&D. Furthermore, the Romer criteria calls for the public provision of R&D, but at the same time it requires that firms need to gain market power over their discoveries in order to provide incentives for them to invest in R&D. I have pointed out that government contracting regulations guarantee the firm a percentage profit. I submit that it is possible, if not desirable, to substitute government contracts for market power. If so, military R&D, because of both its spin-off and profit potential, should meet the Romer criteria. In addition, if the military does meet the criteria, then this presents a guideline for the establishment of other government funded R&D programs. In the next section I will attempt to answer these questions. First, I will look at some specific military programs that are advancing dual-use technology. Then, I will draw generalizations that will apply to all types of government funded R&D.

D. Specific Military R&D programs

The military has established a number of programs dedicated to the development of dual-use technology, but the most effective one is the Advanced Research Projects Agency (ARPA). ARPA directly subsidizes civilian research for dual-use technology. They give out contracts worth approximately one billion dollars a year to more than three hundred corporations and universities. One of ARPA's biggest successes was financing Stanford scientists to set up private computer companies. From this venture Sun Microsystems, MIPS Computer Systems, and Silicon Graphics were created. In another example, ARPA is dispensing thirty million dollars a year to subsidize the creation of High Definition Television (HDTV). For the military, HDTV will advance communication and targeting capabilities. The commercial aspiration is to have HDTV replace conventional TV as well as be used in the monitors of videophones. By subsidizing the production of HDTV, ARPA hopes to get a lower marginal cost of production for both the military and civilian firms and hopes to speed up HDTV's arrival.[17] The estimated commercial availability of HDTV is about two years (1997).

To reward ARPA for its success DoD is giving ARPA more responsibility. To most government departments this would seem like a blessing; however, ARPA administrators are opposed to becoming too large. They feel that their effectiveness comes from their ability to get around the red tape experienced by most government bureaucracies.[18] However, since the military's reliance on dual-use technology is increasing, ARPA's responsibility must increase as well. In 1992 they were put in charge of a new DoD program called the Technology Reinvestment Project (TRP).

TRP is the military's cornerstone for the promotion of dual-use technology and arguably the most efficient way to maintain the military-industrial base. Originally conceived in 1992, TRP's mission is "to stimulate the transition to a growing, integrated, national industrial capability which provides the most advanced, affordable military systems and the most competitive commercial products."[19] Their overall goal is to set up partnerships and cost sharing ventures between military labs and civilian firms. The

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[17] Ibid., p95.
[18] Ibid., p97.
[19] Lessure, Carol A., "Technology Reinvestment Project: Potential Military Bargain", Defense Budget Project, February 17, 1995, p.3.

majority of the partnerships will involve dual-use technology development only, so the DoD can minimize the security risks of working with private firms (classified programs will still remain "black" and out of public stock of information). This goal is basically the same as ARPA's original goal, but now it is more aggressive. With a shrinking defense budget DoD is hoping that this program can help maintain US military readiness and superiority.

Although TRP's budget is relatively small (.02% of the FY96 defense budget), critics contest that this is another attempt by DoD to implement industrial policy.[20] They feel that many of the programs being subsidized have little or no relevance to military objectives, but that the government is just picking and choosing which industries to aid and which not to aid. Currently in Congress, these same critics are lobbying to eliminate TRP's budget altogether. Due to the pressure to reduce the deficit (and hence the defense budget) these critics are perched to get what they want. If the funding for TRP is canceled, then the total amount of military R&D would be reduced. In other words, TRP's money would not be reallocated, but it would simply be lost.

In effort to compromise, TRP has executed some changes. DoD is now reviewing all TRP technology areas to insure military applicability. After reviewing 250 TRP partnerships, funding for those without direct military application was cut.[21] Theoretically, this should slow growth, but it is a necessary step to appease budget cutters. Also, ARPA has modified TRP to speed up the grant approval process in order to remove the lag time between project initiation and completion. ARPA hopes this will

[20] Ibid., p5.
[21] Ibid., p8.

bring about faster results which could aid TRP in its battle for funding. If ARPA can show how helpful it is in advancing both civilian and military technology, some of the pressure to cut its funding should be eased. Unfortunately, by requiring TRP to fund only military specific use R&D, Congress is severely limiting the growth potential created by this program.

IV. From Military to General Government Funding

With the addition of programs like TRP, ARPA is subject to even more criticism. Many people, such as Claude Barfield of the American Enterprise Institute, feel that government investment in specific areas of technology is, in reality, industrial policy. Barfield feels that DoD is using public funds to advance goals of special interest groups and has no right to decide which areas of industry should be subsidized.[22] Some people argue that the promotion of technological advancement should be left to groups such as the National Science Foundation, the Department of Commerce, the Office of Technological Assessment, or the National Institute of Standards and Technology.[23] While still other opponents feel that any kind of government subsidization is de facto industrial policy, and, therefore, will only hurt free market efficiency. Their solution is to promote R&D through tax structure incentives.

Economists as far back as Samuelson have suggested the use of R&D tax credits. However, tax credits will change the amount of production that takes place as well. In

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[22] Weidenbaum, p97.

[23] OTA, NIST, DoC and the NSF are all government sponsored agencies that are held to be more objective than DoD in deciding what type of technology to advance. (Adams, et al., "What transition Will Look Like?", p19.)

rebuttal to the tax incentive approach, an anonymous Director of the Computer Science Lab at MIT, believes that money is made in production; therefore, the government should subsidize innovation and leave production to the firms.[24] If firms were allowed to concentrate on production, then they would earn more money which the government could then tax in order to pay for R&D efforts. Additionally, Albert Link finds that the recent trend in industry has been away from basic research to development suggesting production is more profitable. Moreover, a study by Terleckyj found that the rate of return to firms that invest in R&D is around 30%; whereas, the returns to other firms who benefit from that same technology is around 45%.[25] Therefore, the simultaneous use of technological information leads to growth in the economy. Terleckyj's information points out the positive externality associated with R&D. Also, this evidence implies that growth is endogenous, for R&D is leading to growth in production as well as increasing returns to innovation. Furthermore, innovations when non-rival in nature will have a public good spill-over effect. Overall, theory and empirical evidence indicate that direct subsides are very effective in promoting growth.

Another argument for direct subsides comes from depletion theory itself. As I stated earlier, studies by the RAND Corporation and Lucas (1988) argue that R&D resources and human capital flow from areas of high marginal returns to areas of low marginal returns. According to this evidence, depletion theorists are correct in saying that defense industry is acting like a magnet for R&D funds and human capital. However, I feel that this should actually benefit society rather than deplete it. Therefore,

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[24] Weidenbaum, p103.

[25] Link, p53.

if the government can truly influence R&D and, thereby, influence economic growth, then it should actively use industrial policy to guide R&D efforts. The theory suggests the use of programs such as TRP, so that R&D investment are used for the development of dual-use technologies.[26] In these programs the government is subsidizing the public good, and firms are gaining profit via government contracts (instead of through exploiting market power). Also, the technological advances made by these firms can then be used by all industries.

Government provision should be optimal according to this theory, but if any type of activist policy is undertaken by the government, it must be dedicated and long-term. Several studies have shown that long term efforts to subsidize R&D are (negatively) effected by the "stop and go" investments made by the government over the business cycle.[27] Much of the impact of subsidizing R&D is lost if the government cannot make long term sustained commitments. The bottom line is that in order to achieve maximum effectiveness the government needs to make solid and committed efforts to subsidize R&D of new dual-use technology. By providing this public good, the government will inspire firms to apply this R&D to production efforts. Since firms will no longer bear the full risk of innovation, production decisions can be made efficiently. Once production decisions are on line, firms will earn more taxable profits which should pay for the R&D subsides. Therefore, I conclude that, theoretically, government funding of R&D is both necessary and growth maximizing. If government contracts can be substituted for market

[26] Programs such as TRP can implies that any type of government dual-use technology program should expand growth. In other words DOE, NASA, and NSF sponsored programs should increase growth as well.

[27] Adams et al., "Does the Defense Dollar Make a Difference?" p24.

power and information is truly non-rival, then programs like ARPA and TRP (and similar programs sponsored by DOE, DOC, NSF, etc.) are ideal for promoting growth in technology.

V. Theoretical Model

In order to test the effectiveness of government funded military R&D, I will first look at theoretical models on the optimal level of government spending. Specifically, I will look at the optimal level of total spending as well as dissecting it into its components: military and non-military expenditures. Then, in the next section, I will do an empirical study of the effects of various types of R&D (academic, company, military and non-military) on total factor productivity (TFP).[28] By combining the theory with empirical data, I will draw my conclusions and policy implications.

Many economists, including the previously quoted Lawrence Klein, assert that military spending is not at all productive. To these people an economy without the need for a military would be a much better place. However, the need for the military (and in general the government) does exist. Given the need for a government, I would like to determine if the government is acting in a growth maximizing fashion. Consequently, I use a growth model that incorporates government expenditures. Specifically, I used a model developed from Barro's work on government spending and growth.[29] In an effort to determine the optimal government size, Barro (1990) created a simple model of

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[28] Total Factor Productivity, TFP, is a measure of the level of technology. In the standard Cobb-Douglas approach: ($Y=AL^{\beta}K^{1-\beta}$) the TFP is equivalent to A.

[29] The model is a combination of Barro(1990) and Barro, Robert J. And Xavier Sala-i-Martin, Economic Growth. New York: McGraw-Hill, 1995.

government spending with constant returns to scale. His growth model takes the standard form in which the consumer wants to maximize lifetime utility subject to a capital stock growth constraint. (See Appendix I for a more detailed explanation.) Also, his model includes a government spending component which is financed by a flat rate income tax. By creating such a tax mechanism, Barro can solve his problem for the optimal government size simply by finding the optimal flat rate income tax (since the tax rate is the ratio of government spending to total output). More explicitly, the ith firm production function, the optimal growth rate, and optimal tax rate are as follows:

$$Y_i = AL_i^{1-\alpha} K_i^{\alpha} G^{1-\alpha}$$

$$\gamma = (1/\theta)\left[\alpha A^{1/\alpha}(L\tau)^{(1-\alpha)/\alpha}(1-\tau) - \delta - \rho\right]$$

$$optimal\ \tau = (1-\alpha) = G/Y$$

where: θ = *elasticity of substitution*; δ = *depreciation* rate; ρ = *discount* rate;

$A = TFP$; $L = labor$; $K = capital$; $G = government\ spending$;

$\tau = G/Y$ = income tax rate; *and* γ = *growth rate*

α *is constant*, $0 \le \alpha \le 1$

Barro finds that growth is maximized where the flat rate income tax (or simply tax rate) is equal to the government share of production.[30] Furthermore, the growth rate equation that Barro finds measures the trade-off between the benefits of taxation (i.e. government services) and the negative affect taxation has on the marginal product of capital. This trade-off is illustrated below.

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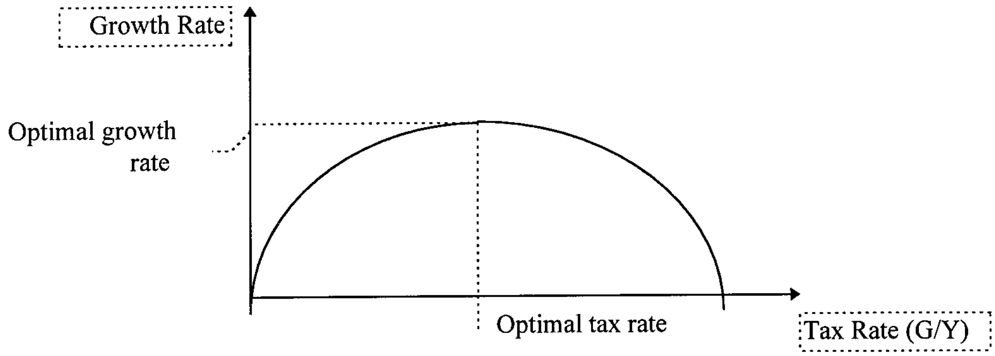
[30] In his empirical simulations Barro finds that the optimal government spending to output ratio (tax) is 0.25.

Figure 2



This "Laffer-like" curve is only a rough estimation of the positive and negative trade-offs of government spending; however, it represents the fact that a growth maximizing tax rate (government size) exists. Overall, Barro's model is very simplistic, yet it shows the conditions that maximize growth with the existence of a government.

Realizing that government is both necessary and productive, I wanted to further understand the impact that government has on growth. Specifically, my goal was to discover the effects of military and non-military R&D on growth. To determine this, I made Barro's model more complex. First, on the theoretical level, I expanded Barro's model to include two types of government spending: military and non-military. In turn, the production function was altered as follows:

$$Y = AL^{1-\alpha}K^{\alpha}\left[G_1^{\eta}G_2^{1-\eta}\right]^{1-\alpha} \textit{ where } \; 0 \le \eta \le 1 \qquad (5.1)$$

Where η is the constant of government sustitution
G_1 is government spending on the military
G_2 is government spending on non - military.

By using this specification, I am able to breakdown government spending into two components and still maintain constant returns to scale. However, one problem exists in the real life application of this: estimating the constant of government substitution and the government spending value share. (This problem will be discussed further in section six.) Another advantage of this model is that the procedures of Barro can still be used to determine the optimal growth path. A full mathematical derivation of my results can be seen in Appendix I, but the main results are as follows:

$$\gamma = 1/\theta\left[\alpha A^{1/\alpha}\left(L\tau_1^{\eta}\tau_2^{1-\eta}\right)^{(1-\alpha)/\alpha}\left\{1-\tau_1-\tau_2\right\}-\delta-\rho\right] \qquad (5.2)$$

$$\textit{where } \tau_1 = \eta(1-\alpha) = G_1/Y \qquad \text{and } \partial\tau_1/\partial\eta > 0 \qquad (5.2a)$$

$$\textit{and } \tau_2 = (1-\eta)(1-\alpha) = G_2/Y \qquad \text{and } \partial\tau_2/\partial\eta < 0 \qquad (5.2b)$$

As in Barro's model, the optimal flat rates of income tax are equal to the government share of production. Intuitively, this makes perfect sense. By taxing the private sector, the government is removing resources from private sector productivity. Therefore, the government should only remove from productivity what it replaces with its own services. If it over-taxes, it creates a lower than optimal after tax marginal product of capital for the private sector. Likewise, if it under-taxes, the full potential of government productivity is not realized. In other words, the Barro trade-offs illustrated earlier still exist, only now the picture would be a hill in three space.

After understanding the growth maximizing condition, I desire to find out if the US government is practicing optimal behavior. To do this, I must estimate a number of parameters. The key, or most difficult, estimate is that of the constant of government substitution. Once this is done, I need to return to the question at hand: is government funded R&D optimal? Therefore, after I econometrically validate the production function that I have specified, I will estimate the TFP growth rate and see how the various types of R&D effect technological growth. In the next section, I create an empirical model to estimate the production function. Using the parameter estimates I obtain, I will find out if the government is operating at the growth optimal size. Then, after estimating the TFP growth rate, I will determine if the government is behaving in a growth maximizing way with respect to R&D spending.

VI. Empirical Model

A. The Production Function

After finding the theoretical optimal tax rates, I need to estimate the size of the input value shares and find the total factor productivity growth rate. To accomplish the first step, I used the empirical work of Aschauer (1989) as my foundation. He found that government spending on various types of infrastructure increased the productivity of private sector. The majority of his "core" infrastructure consists of highways, airports, mass transit, sewers, gas and electric utilities, and water systems. He found the "core" to have the most explanatory power for production. However, he also found that military capital had little or no impact on production.[31] Kormendi and Meguire (1985) also concluded the same thing; the level of government spending has no affect on output or average growth rates. However, others such as Grier and Tullock (1987), Landau (1983), and Barro (1989) have all concluded that government spending has a negative impact on

[31] Two points to note: 1) Aschauer did this study with funding from the Highway Department, 2) He also found government expenditures on educational capital to be unproductive (implying education is unproductive). Therefore, I view his results with some criticism.

growth.[32] Overall, current empirical results indicate that government is, at best, a "necessary evil".

Using this implication as my a priori intuition, I followed the estimation procedures of Aschauer (1989). The first step was to perform a log linear transformation on my production function. Since I used a Cobb-Douglas type production function, after the log-linear transformation was performed, the OLS estimates attained represent the output elasticity with respect to each input, or value shares. Typically, when constant returns to scale are employed, the labor share, or output elasticity of labor, is about 0.6; whereas the capital share is about 0.4. Therefore, I performed OLS keeping in mind these share values and the implications of previous studies. Then, Aschauer (1989) added a deterministic time trend variable, t, to account for exogenous changes over time and capacity utilization variable, cu, to include the effects of the business cycle. Since the capacity utilization rate will effect the amount of capital used each period, I multiplied the capital stock by cu.[33] The general model then became:

$$ln Y_t = \beta_0 + \beta_1 ln L_t + \beta_2 ln(K*cu)_t + \beta_3 ln G_{1_t} + \beta_4 ln G_{2_t} + \beta_5 t + \varepsilon_t \qquad (6.1)$$

where ε_t *= error which is a random walk*

The correct way to measure this function is to use aggregate annual data. Unfortunately, macroeconomics data of this type is nonstationary. The problem with nonstationary data is that the first and second moments of the series are dependent on

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32 Although Barro does admit that government spending may be utility enhancing, just not growth optimal. (Barro 1990 p.S123-4)

33 This is consistent with Tatom (1981) as quoted in Aschauer (1989). I also ran the regressions with cu and K taken separately; however, combining the two gave a better capital share value. Furthermore, an F-test was done to ensure that the coefficient values for cu and k were equal (i.e. B_2=B_6). I could no reject that hyothesis with an F-stat of 0.4

time. Therefore, I must take the first difference of this equation to remove the effects of time on the variables.[34] Normally, a transformation of this type would produce growth rates as estimation coefficients; however, in this case, the coefficients will maintain their original values and will still represent the value shares. The final model then becomes:

$$\Delta \ln Y_t = \beta_5 + \beta_1 \Delta \ln L_t + \beta_2 \Delta \ln(K * cu)_t + \beta_3 \Delta \ln G_{1_t} + \beta_4 \Delta \ln G_{2_t} + \nu_t \qquad (6.2)$$

where $\Delta lnX_t = \ln X_t - \ln X_{t-1}$

(Notice that by using this transformation, β_0 *will drop out and be replaced by the coefficient from the time trend variable,* β_5*. Also, the error term* $\nu_t = \varepsilon_t - \varepsilon_{t-1}$*. Since* ε_t *was a random walk, the new error term* ν_t *is now i.i.d.*
A complete mathematical derivation can be seen in Appendix III.)

To estimate equation 6.2, I used aggregate annual US data spanning the years 1967 to 1993. Furthermore, I converted all monetary observations to constant 1987 dollars. The labor variable was measured as the total number of hours worked. I used GDP as my measure of output. The capital stock was determined using the perpetual inventory method. For this, I used Christensen and Jorgensen's (1969) benchmark year of 1929 and added net fixed nonresidential investment.[35] Non-military government spending was measured by government investment (since theoretically only the productive portion of government spending should be included in the production function.) Data on government capital was taken from National Income and Product Accounts published by the Department of Commerce's Bureau of Economic Analysis. Finally, military spending was measured as government purchases for national defense.

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[34] To ensure nonstationarity of my log differences, I checked all series with the ADF uroot test.
[35] Barro suggest starting with a benchmark year that is significantly earlier than the first year of you data set.

Other than noted above, all data comes from the Economic Report of the President 1994. The results of my regression are in Table 1.

Table 1

Variable	Coefficient	T-stat
Constant	0.011	4.73
ln L	0.62	2.12
ln (K x cu)	0.22	1.77
ln G_1 (non)	0.007	0.24
ln G_2 (mil)	-0.03	- 1.08
Other	Significant	Indicators
Adj R^2	0.841	S.E.R. = 0.008
Durbin Watson	2.37	$d_l = 1.08$ $d_u = 1.75$
Goldfeld-quandt	3.26	$F_{crit} = 5.05$

As can be seen above, my results almost totally agree with my a priori predictions.[36] The labor and capital shares are reasonably close to real life with values of 0.62 and 0.22 respectively. (Although the capital share is only significant at the 90% level.) Despite the fact that the coefficients for military and non-military spending are insignificant, they agree with the previous empirical studies (i.e. there is little or no impact of government spending on output). However, as with all time series analysis my results must be checked for both autocorrelation and heteroskedasticity. First, to check for autocorrelation I used the Durbin Watson statistic. The calculated d-statistic of 2.37 is not within the limits specified in Table 1. This could indicate autocorrelation; however, a d statistic of greater than two normally indicates negative autocorrelation. In time series work, such as this, the intuition is for positive autocorrelation. Because of these doubts, I ran four more checks for autocorrelation. The first was a graphical test in which I plotted

[36] The actual microTSP output can be seen in Appendix II. Also in Appendix II, are the results from the estimation of equation 6.2a-- the tax ratio form of the production function. These results mirror those already presented, so they are not discussed in the paper.

the residual terms from the regression against their lagged values. The pattern created by this plot appeared to be random and can be seen in Appendix II, Figure 4. The second, third and fourth tests were the Chi-squared test of independence of residuals, the Breusch-Godfrey test, and the Box-Pierce test. I found no evidence of autocorrelation using any of these tests. Therefore, I conclude that no autocorrelation exists.

Next, to check for heteroskedasticity, I first made a scatter plot of the dependent variable (lny) against the squares of the residual terms. (This plot can be seen in Figure 3 located in Appendix II). The scatter plots appear to be fairly random indicating that my error terms were homoskedastic. Second, I performed the Goldfeld-Quandt test. After rank ordering the observations of my original data, I ran separate regressions of the first ten and last ten using the same specification as equation (6.2). I then used the sum of squared residuals from each regression to construct an F-statistic. In this test the null hypothesis is that the errors are homoskedastic. Since, my F-statistic of 3.26 was below the critical value of 5.05, I cannot reject the null hypothesis. Finally, I used the autoregressive conditional heteroskedasticity (ARCH) test. I found the F-statistic to be 0.33 which is significant only at levels of 56% and lower; therefore, I am content that my errors are homoskedastic. Overall, since I find no problems with the OLS error term assumptions, I conclude my estimation results are sound.

Unfortunately, although my results are sound, they discredit the production function I have specified in equation 5.1. My theory gives much more weight to the government sector than what seems to exist in real life. In my theoretical model, I assume constant returns to scale exists not only between capital and labor, but between capital and total government spending as well. Given my regression results, this second assumption does not appear to be valid; therefore, I find it impossible to calculate a logical value for the constant of government substitution. However, my theory may not be totally incorrect. In fact, it is possible that some cointegration exists between the output variable (real GDP) and all of the input variables including government spending. In other words, OLS may not be the best way to measure this production function.[37]

On the other hand, the OLS results hint that the overall model has constant returns to scale. I used an F-test to check this suspicion. I ran a restricted least squares model in which I assumed that the total of all coefficients was equal to one. After adjusting the model accordingly, I ran the OLS regression to obtain the restricted sum of squared residuals (SSR). Then, I created an F-statistic in the following manner:

Fstat = [(restricted SSR) - (unrestricted SSR)]/[(unrestricted SSR)/22)]

= 1.207.

This F-statistic is smaller than the critical value of 4.3. Therefore, I must accept the hypothesis that the model has constant returns to scale. In light of this information, I re-specified my production function to take on the following form.

[37] As a cointegration test, I first found the residual terms from the regression of (6.1). Then, I regressed equation (6.2) using the lagged terms of the input variables along with the lagged values of the residuals from the first regression. I found that the residual terms had a coefficient of 1.31 and a t-stat of 4.32, indicating that conintegration exists between the variables. Therefore, I cannot totally dismiss the production function that I have specified in this paper.

$$Y = AL^{1-\alpha-\beta-\gamma} K^{\alpha} G_1^{\beta} G_2^{\gamma} \quad where\ \alpha + \beta + \gamma = 1 \qquad (6.3)$$

After dividing both sides by capital and taking the natural log, I have the following estimation equation: *(6.4)*

$$lnY_t - lnK_t = \mu_1 + \mu_2 \left(lnL_t - lnK_t\right) + \mu_3 \left(ln\,G_{1_t} - ln\,K_t\right) + \mu_4 \left(ln\,G_{2_t} - ln\,K_t\right) + wage_t + t + e_t$$

Unlike the log difference form I described earlier (6.2), this equation follows the procedures of Aschauer(1989) exactly. He takes the ratio of all factors with respect to capital, as I have done above. For this estimation, all variables were calculated the same as previously specified. This time, however, the deterministic time trend variable is left intact, and I added real wage variable to account for improvements in worker quality. The results of the regression of equation 6.4 are below.

Table 2

Variable	**Coefficient**	**T-stat**
Constant	-8.89	-8.35
lnL - ln(K*cu)	0.80	8.64
lnG_1 - ln(K*cu)	0.069	2.35
lnG_2 - ln(K*cu)	-0.01	-0.56
wage	0.13	.937
t	0.009	9.84
Other	**Significant**	**Indicators**
Adj R^2	0.843	S.E.R. = 0.008
Durbin Watson	1.27	d_l = 1.08 d_u = 1.75

Despite the seemingly robust results (seen in Table 2 and Appendix II), the model is not valid. After performing the transformations and adding a time trend variable, Aschauer (1989) is content to conclude that his data is stationary. However, I do not find this to be the case. I performed the Augmented Dickey-Fuller (ADF) test to determine stationarity. (The results can also be seen in Appendix II, Figure 5) Using this test, I found that the data for ln(G_1/K) and ln(G_2/K) was nonstationary. Therefore, the regression estimates are invalid. Likewise, I must dispute the findings of Aschauer(1989) on the same basis. His empirical analysis claimed to yield very robust results; however, if his data is nonstationary, his results are subject to criticism. Because of the problem with non-stationarity, I will use the estimation of equation 6.2 as my preferred model.

B. Growth

Despite the disagreement between theory and reality, my model does present some interesting growth ideas. First, if the taxation system is established in the manner I have described (i.e. a flat rate tax to separately finance military and non-military spending), then the optimal growth path would entail a overall tax rate of 0%. Since neither government investment share nor military spending share can be proven to be anything but zero, they are not adding anything to production. Therefore, they should not be tax financed. However, in real life both government and the military are utility enhancing, so they need to be provided. Consequently, the government is forced to "over-tax" to pay for its expenditures. Following the reasoning of Barro (1990), if the government over taxes then growth will be less than it would be otherwise, ceteris paribus. [38]

If my regression is correct and government spending is not productive, then my production function is invalid. However, I will digress for academic purposes to determine the optimal growth path if it were the case that the government were

[38] Unfortunately, the growth equation cannot be estimated when either (let alone both) tax rates are 0%. This would cause the Cobb-Douglas portion of the equation to be zero, and then overall growth would be negative. Therefore, I must estimate the results hypothetically, assuming that government spending is productive.

productive. Since I cannot logically calculate the value of the constant of government substitution from my empirical analysis, in order to find my theoretical growth maximizing point, I also had to find the theoretical optimal value of this term. I attempted two different methods of determining this value. First, I assumed that the government was behaving in an optimal fashion. In other words, I assumed that it is taxing at a level equal to its share in production. Second, I attempted to solve the optimal taxation question by assuming that only the actual constant of government substitution is correct. More specifically, I used the actual values of G_1/Y and G_2/Y to calculate the constant of government substitution. Then, I assumed that this level is optimal and combine it with the actual level of capital share. By doing this, I should be able to determine the optimal level of taxation.

For my first attempt, I used the real life values of the ratios G_1/Y and G_2/Y to determine the optimal level of taxation. In 1993, the actual value of G_1/Y was 0.0256 and the actual value of G_2/Y was 0.0476. If the government was behaving optimally, then the flat rate income tax it enforces on society should equal 7.2%. Clearly, the level of income tax actually enforced in 1993 was larger than 7.2%. Once again, this is evidence that the government is over-taxing; thereby, causing reductions in growth. However, the only way to obtain the value of 7.2% was to use an inaccurate measure of the capital share (0.9 rather than 0.4).

Because of this inaccuracy, I also looked at tax optimization by assuming that only the constant of government substitution was correct, but not the overall level. For this method, I combined the actual ratios G_1/Y and G_2/Y with their theoretical optimal values. Then, I calculated the value of the constant of government substitution to be 0.35. Using this value in conjuction with the actual value of the capital share, 0.4, I found the optimal overall tax rate to be 60%. In this case, non-military expenditures must be financed with a flat rate income tax of 21% and military expenditures must be financed by a 39% tax. These values of taxation are much more believable in terms of what is seen in real life. However, because in the empirical analysis I found that government spending is not that productive, I cannot attach that much confidence to these estimates.

Despite the disparity between theory and reality, I used the real life value of the constant of government substitution to estimate the growth rate of the economy (once again for academic purposes). In addition to this value, I used the parameters specified by Barro (1990). Combining all these values and substituting them into equation (5.1), I found the optimal growth rate to be 0.0683. (Full results are seen in Appendix III.)

Once again, I must stress that this calculation was made for academic purposes only, and does not carry any weight in reality. The two important implications to draw from this section are 1) the government is over-taxing society; therefore, it is hindering economic growth, and 2) although the actual estimate is inaccurate, this growth model still accurately represents the trade-offs involved with government expenditures and growth.

C. Total Factor Productivity

Despite its propensity to over-tax, the government could also have positive impacts on growth. As I described in sections I-IV of this paper, R&D is a public good and should be provided by the government. Therefore, the positive spill-overs of government R&D (both military and non-military R&D) could off-set the negative effects of over-taxation. These effects would show up in the production function as increases in TFP (or the constant term, "A"). In the this section, I will test this theory by examining the relationship between TFP growth and government funded R&D.

After estimating the production function and looking at some growth issues, I return to the issue of government spending on military R&D and technological growth, or total factor productivity growth. TFP is a measure of technological process. In 1957, Solow found that population growth and savings could not account for the massive growth rates in the US. Furthermore, Landau (1989) tells that with constant returns to scale, technological growth may account for as much as three-fifths of output growth. To illustrate, remember from equation 6.2 that the basic growth equation (or log difference equation) is:

$$g_y = g_t + s_k g_k + s_l g_l.$$

Where g_y is output growth, g_t is output growth attributed to technological advancement, g_k is capital growth, g_l is labor growth, s_k is capital share and s_l is labor share. With constant returns:

$s_k = (P_k K) / (P_y Y)$ where P_i is the price of the good i

and, therefore:

$$g_y = \{g_t / (1 - s_k)\} + g_l,$$

or with typical capital share of 0.4:

$g_y = 1.67g_t + g_l.$

Therefore, Landau(1989) finds that technological advancement accounts for the majority of the growth in production. Empirically, the Bureau of Labor Statistics has found that over the period 1948-1985 the US private business sector grew at an average annual rate of 3.2%. Of this increase, 1.2% is attributed to capital, 0.6% to labor, and 1.4% to TFP. Clearly, technological progress plays a major part in growth. This realization is nothing new, but great controversy still exists over the relationship of various inputs to this TFP. Most contemporary endogenous growth economists believe that technological growth is a result of undertakings to maximize long-term growth. In other words, technological progress is a conscious effort, not just an exogenous spillover of other activities. Unfortunately, one of the best ways to measure TFP is to treat it as a residual, not unlike Solow did in 1957. Trying to measure technological progress in any other fashion is beyond the scope of this paper. Therefore, I will use the work of Griliches (1973) to model the affects of R&D on growth. He pioneered this process in which the TFP growth rate is measured from the production function data. Similar to the process described by Landau (1989) the mathematical derivation is the following:

$$\begin{aligned}\ln(A_{t+1} / A_t) &= \ln(Y_{t+1} / Y_t) - (1-\alpha)\ln(L_{t+1} / L_t) - \alpha\ln\left(K_{t+1} / K_t\right) \\ &\quad -(1-\alpha)\eta\ln\left(G_{1_{t+1}} / G_{1_t}\right) - (1-\alpha)(1-\eta)\ln\left(G_{2_{t+1}} / G_{2_t}\right) \qquad (7.1)\end{aligned}$$

In addition to Landau's capital and labor growth, I have added the growth rates of military and non-military spending. This should allow me to test the hypothesis that government spending on R&D can offset the negative growth impacts of over-taxation. Unfortunately, in order to generate the observations for $\ln(A_{t+1} / A_t)$, I would have to assume that the coefficient values are constant over time and are equal to the coefficients from equation 6.2 that I estimated with OLS (see Table 1). As I have already stated the value of the constant of government substitution was insignificant; therefore, any numbers I generate with this estimate would also be inaccurate.[39] In an attempt to correct this problem, I gathered data published by the Bureau of Labor Statistics (BLS) on what they call Multifactor Productivity (MFP).[40] By this definition, MFP (or TFP) is the ratio of output to input in the nonfarm business sector. The levels of capital and labor inputs are calculated using the Tornquist aggregate, and the level of real output is the Fisher Ideal quantity index.[41] (The values obtained by this calculation can be seen in Appendix IV listed as MULTI.) One of the nice features of this data is that it excludes government enterprise. In other words, by using this data for my regression, I can fully measure the positive externalities of government funded military R&D on the private sector.

Before, I can run the my regression I needed to transform the data in two ways. First, I took the natural logarithm of the ratio of TFP this period to TFP last period. This will give me the TFP growth rate. Second, I needed to add a deterministic time trend variable, a capacity utilization rate variable, and a real wage variable. The first two variables are added for reasons already mentioned. However, a real wage variable is added to account for worker quality over time. I feel it is necessary to include these

[39] Other empirical evidence would lead me to believe that the value share are not constant over time. More expressly, the US has become more capital dependent over time. In 1922, Cobb and Douglas found that the capital share was approximately 0.25.[39] Whereas, studies from more recent years indicate that the capital share is somewhat higher at 0.41.[39] For this reason, I must conclude that estimates for the TFP growth rate generated with constant value shares would be inaccurate.

[40] Data from the BLS was gained over the internet courtesy of Larry Rosenblum at http://stats.bls.gov/labstat.htm

[41] In the Tornquist method, inputs are broken down into sub-sections which are then weighted by their respective levels of compensation (hourly wage, rental price, etc.).

variables because the MFP data lumps technological change in with all other types of productivity increases. Therefore, I must include other variables to account for these types of changes.

Once the TFP growth rate is determined, I regress it against the growth rates of various types of R&D. To create more useful information, I have dissected R&D spending into four categories: company funded industrial, non-federal government funded academic, federal military, and federal non-military. The general form of the regression is as follows:

$$g_t^{TFP} = \varphi_0 + \varphi_1 g_t^A + \varphi_2 g_t^C + \varphi_3 g_t^{NoN} + \varphi_4 g_t^{DoD} + \varphi_5 wage_{t-1} + \varphi_6 cu_{t-1} + \varphi_7 t + e_t \qquad (7.2)$$

where g_t^i is the growth rate of factor i in time period t;

$i \in \left(\text{TFP, (A)cademic, (C)ompany, (NoN) - military, and DoD}\right)$

e_t is the error term and wage and cu are the natural logs of the real wage rate and capacity utilization rate respectively.

Before I proceed with the estimation results, I will recap my a priori intuition (which I described more thoroughly in sections I-IV). First of all, government funding of R&D should have the most impact on growth because R&D is a public good. Second, of the two types of government funding, non-military should have a larger effect since, theoretically, non-military R&D is more closely related to private sector production. Third, academic R&D should have a substantial effect as well because academic funds promotes the growth of both technology and human capital. Next, company R&D should have the smallest impact, for although the company funds will promote long run growth, firms have to shift money from current production to subsidize innovation. Moreover, company's try to protect their R&D efforts with patents and copyrights. These efforts prevent the simultaneous use of technology. Consequently, I feel that growth is enhanced when other sources provide the innovation and then allow firms to use it in production. Fifth, the capacity utilization variable is included and lagged one period because the amount of capacity used in the last period will have a negative effect on growth in the current period. This is true because when a firm is operating at close to full capacity, it will be concentrating more on production than innovation; therefore, less money will go to R&D and the TFP growth rate will be decreased. Finally, the TFP growth rate also incorporates the effects of labor quality; therefore, I must include a real wage variable. Since a higher real wage in the last period will lead to higher growth in the current period, the wage variable is also lagged one period as well.

Keeping this intuition in mind, the final step in my model preparation was to determine the complex lag structure. Intuitively, the funds spent on R&D today may take years to trickle down to production. As I have already suggested, the government should finance the beginning of the learning curve. This could entail a huge lag time between when money is spent and when it has an impact. For example, money spent in the 50s and 60s on computers is clearly having a huge impact on current productivity. Furthermore, most experts agree that the average lag time between R&D and production is approximately 5 to 8 years (with military efforts taking longer than the others). My limited data set will hinder my ability to capture such effects. Despite this possible problem, I incorporated a 5 to 8 year lag. This will alter the regression function in that each component of R&D will now be subscripted by t-x, where x is the size of the lag.

Since the lag structure is unknown, I attempted regressions on a vast number of various models. I tested them with data from the National Science Foundation's Science and Engineering Indicators. The observations are real, aggregate, annual US data for the years 1967-1993 with 1987 as the base year.[42] Academic R&D was measured as the amount of non-federally funded academic R&D. Company R&D was proxied by company funds for industrial R&D. Non-military R&D was measure as all federal funds used for R&D that did not go to DoD. Finally, military R&D was measured as all federal R&D funds given to DoD.

Using this data I created my "best", or most preferred model. My selection criteria for the "best" model was the highest overall F-statistic combined with the best individual t-statistics. Of course, before this determination was made, I verified that the candidates for "best" model were free from autocorrelation and heteroskedasticity. In the end, I found the "best" model to be:

$$g_t^{MFP} = \varphi_0 + \varphi_1 g_{t-4}^{A} + \varphi_2 g_{t-5}^{A} + \varphi_3 g_{t-4}^{C} + \varphi_4 g_{t-5}^{C} + \varphi_5 g_{t-4}^{NoN} + \varphi_6 g_{t-5}^{NoN} + \varphi_7 g_{t-4}^{DoD} + \varphi_8 g_{t-5}^{DoD} + \varphi_9 cu_{t-1} + e_t \qquad (7.4)$$

Results for the estimation of this equation are seen in Appendix IV. (The microTSP output is marker by its equation number (7.4) and the graph of the equation and the autocorrelation and heteroskedasticity tests are seen in Figures 6-10.) A summary of the results is below.

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[42] Data for Federal Funds for research and development could only be obtained back to 1967.

Table 3

Variable	Coefficient	T-stat
Constant	1.03	4.18
A(-4)	-0.65	-5.64
A(-5)	0.29	3.29
C(-4)	-0.23	-3.46
C(-5)	0.06	1.14
NoN(-4)	-0.11	-3.37
NoN(-5)	0.07	2.07
DoD(-4)	0.08	1.93
DoD(-5)	0.12	2.10
cu(-1)	-0.22	-4.12
Other	Significant	Indicators
Adj R^2	0.84	S.E.R. = 0.007
Durbin Watson	2.25	$d_l = 0.46$ $d_u = 2.6$
ARCH F-stat	0.33	Prob = 0.72

Using the BLS measure of TFP, I was able to gain significant results. As predicted, the once lagged value of the capacity utilization rate had a strong negative impact. For every 10% increase in capacity utilization in period t - 1, a 2.2% decrease occurs in TFP growth in period t. Despite this foreseen outcome, the rest of the model had curious implications. Except for military R&D growth, all other growth variables exhibit an interesting anomaly. They all had significant negative t-statistics when lagged four periods, and they also had positive significant t-statistics when lagged five periods. I have one possible explanation for this fact which I will illustrate with a simple example.

Suppose that in time period t firms have two choices: innovation and production. Production will create profits in period t, and innovation will increase profits in time t+5.[43] However, innovation must be financed by current production. Likewise, current

[43] This argument could also be expanded to academic R&D. For instance if Penn State had two options: invest in football and receive immediate profit or invest in R&D and hope to receive profits sometime down the road. The same fourth year discrepency may take place. Another possible explanation for negattive fourth year lag in academic R&D is that it is often times financed by private companies; therefore the production innovation decision of the firm could rub off onto the academic world.

production will suffer if resources are devoted to innovation. If it actually takes five years for innovation to pay off, then production in the fourth year will have been severely hurt by four years of successive innovation expenditures. Consequently, productivity growth over the four periods prior to the date of innovation would be lower than it would have been otherwise (i.e. period t+4 would have lower TFP-- remember that TFP includes things other than technological development). Thus, the negative coefficients of the variables that were lagged four periods.

If this is the case, then why was the growth rate in military R&D not subject to the same phenomenon? One possible reason is that the coefficient on DoD(-4) is only significant at the 90% level; therefore, the estimate just might be inaccurate. Another possibility is that military R&D goes into effect more quickly than the other forms of R&D (although this in contrary to my suspicions). Or, it just may be that programs ARPA (including TRP both of which I described in the background section) make military R&D more powerful than the other types. Of course, these are all just theories. The most logical explanation is that this is a reaction to the small data set (i.e. I cannot approximate the true lag structure). The bottom line, however, is that I cannot explain this phenomenon.

On the other hand, when simply the estimates for the five year lags are examined, I find that, for the most part, they agree with my a priori intuition. More specifically, I found that growth in academic R&D had the highest impact on TFP growth. A 10% change in the academic R&D growth rate led to a 2.6% increase in the growth rate of TFP when everything else is held constant. This large increase can be attributed to both the increase in technology created by academic R&D and the increase in human capital that it creates. I was surprised by the size of academic R&D's impact but not disappointed. The second largest increase was attributed to military R&D growth, for a 10% increase in the military R&D growth rate relates to a 1.2% increase in TFP growth. The military's contributions are large because they finance the beginning of the learning curve. The innovations that they spur have economy wide impacts and because the government contract works as a profit incentive while at the same time provide the (semi-)free flow of information between all producers. The growth in non-military R&D has the next highest impact. Unfortunately, this smaller effect is opposite my reasoning. I hypothesized that if military R&D was effective, then non-military efforts (which are presumably more relevant to production) would have a greater impact. Clearly, non-military R&D still affects TFP growth for reasons similar to those for the success of military R&D. However, the military's vast efforts to improve computers and communication methods probably ties them more closely to the overall growth rate of TFP. Finally, I found that the growth rate of company funded industrial R&D had little relation to the growth rate of TFP. This does not totally agree with my intuition, but it does have some interesting policy ramifications. If company R&D is less successful at promoting technological growth, then R&D should be left to the government and the academic world. This implication is in total agreement with my intuition. More specifically, I hypothesized that government spin-off technology does still exist and strongly promotes growth. Therefore, the government should at least continue to provide R&D funding, if not do more to increase the development of spin-offs.

This discovery also provides two insights into government contracts. First, they are in fact a good substitute for monopoly rents. The large impact of government R&D spending on TFP growth leads me to believe that many firms are using government contracts in this fashion. Second, this evidence implies that government contracts could also be used as a growth inspiring mechanism which could offset the effects of over-taxation. For instance, as one possible idea, the government could subsidize R&D as part of contract price. (i.e. the government could require that $100,000 dollars from a contract payment must be used for R&D.) This would allow government contractors to maintain profits, but it would also require that growth ventures are undertaken. This evidence opposes the current system under which many government contractors are required to put forth a dollar of R&D funds for every dollar the federal government provides.[44] My results imply that this type of matching policy is not growth optimal. Therefore, if the government wishes to maximize growth is should simply provide R&D funds and let the individual firms make their own production and innovation decisions.

Of course, the depletion theorist would probably argue that growth in military R&D is only more growth inspiring because the military sector is hoarding the majority of R&D resources. This is certainly a possibility, but I will leave that to further study. For now, I am content to conclude that military R&D is growth inspiring; therefore, it is possible that military and non-military R&D efforts when combined may offset the negative growth effects of over-taxation. The determination of the actual size of the positive and negative growth ramifications is also left to further study.

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[44] Lessure, Carol A., "Technology Reinvestment Project: Potential Military Bargain," Defense Budget Project, February 17, 1995, p.1.

VII. Conclusions and Policy Implications

In the early stages of this paper, I described the basics of the theory of growth as well as explored its applicability to government military R&D spending. To summarize, endogenous growth theory tells us that technological advancement, like information, is non-rival in consumption and is a public good. Furthermore, it describes the profit incentives necessary to entice firms to invest in discovering technology. These two ideas seem to contradict each other, for one calls for public provision of technological advancement; while the other calls for monopoly provision. However, government subsidized R&D fills both of these requirements. On the one hand, the government is subsidizing R&D to provide for the public good. And, on the other hand, it inspires firms to apply this R&D by offering profit incentives via government contracts. Theoretically, this is precisely the kind of endeavor which should promote technological growth.

In sections II and III, I examined the specific issue of military R&D. Advocates of military R&D agree with the theory described above. They point out the successes of past military R&D as well as the current US advantage in the high-tech capital goods sector as example of how military R&D promotes growth. On the other hand depletion theorists argue that the military is not living up to its spin-off potential. Moreover, the military is stealing human capital and resources and bringing them to areas of lower productivity. Still other opponents contend that government R&D is industrial policy. Numerous studies indicate that the government can influence the secular distribution of firms' R&D funds. Therefore, people's concerns that politicians are using R&D funds as industrial policy are very valid. However, because both positive and negative sides exist in this debate, I found it necessary to empirically study the effects of the various types of R&D before drawing any conclusions.

In order to accomplish a study of this scope I needed to follow a number of steps. In the first step, I needed to define a theoretical model. In creating this model, I relied heavily upon the work of Barro (1990). From his simple government spending growth model, I created a production function and determined the optimal growth path that allowed me to look more specifically at the issues of military and non-military spending. I found, as Barro did, that growth is maximized when the government implements a flat rate income tax on society that is equal to its share in production. In other words, the government must perfectly balance the weight of its inefficiencies against the benefits of its services. This conclusion is not profound, but it shows the trade-off involved when the government exists as well as necessary conditions for optimal growth.

Knowing how government should behave, leads me to the second step in the process. More specifically I needed to determine if the government was in fact behaving optimally. To answer that question, I first had to validate my production function. Although the results of my analysis were robust, they did not agree with the theoretical production function I created. According to my analysis, both government spending on capital and government purchases for the military had no significant affect on production. This is in agreement with the majority of previous empirical analysis. Furthermore, since the government sector does not appear to be productive, but it still exists. The government is forced to exact higher taxes on society than are growth optimal in order to finance its expenditures. Therefore, the government is over-taxing and economic growth is hurt.

Once I established the government was "too big", the final step was to determine the effects of government funded R&D on growth. Intuitively, research and development is a public good and government funding of R&D is growth optimal. Therefore, the positive impact on growth of government R&D (both military and non-military) may offset the negative impact of over-taxation. To discover if this was occurring, I modeled TFP growth as a function of the growth rates of military, non-military, academic, and company R&D funds. This first was done in the standard Griliches (1973) form. However, to follow this form I had to assume that the input shares were constant overtime as well as identify the proper lag structure. Using this process, I obtained results that were far from reasonable. Unfortunately, I cannot tell if this is due to the small size of my data set, the mis-specification of the lag structure, or the assumption of constant input shares.

In an effort to dispel some of the uncertainty, I tried using a different data set. For this I used the Bureau of Labor Statistics measure of multifactor productivity. Doing the analysis in this manner removes the assumption of constant input shares but still has problems with specification and data set size. Fortunately, this new data provided me with robust results. Despite the anomalies that occurred when the variable were lagged four periods, the results agree almost entirely with my a priori predictions. More specifically, academic R&D growth inspired growth in TFP because it not only increases technology but human capital as well. Moreover, both types of government funded R&D

growth also inspired growth in TFP. This evidence backs up my theory. (remember that my analysis of endogenous growth and military R&D indicated that government provision of R&D via programs such as ARPA and TRP should inspire growth. Finally, I found that company funded R&D growth was not significantly related to TFP growth. This result also backs my theory. In other words, innovation should be provided by the government and the academic world, not the companies themselves.

In light of this information, I feel that the government should provide more funds that subsidize R&D or even alter its contracting structure, so as to provide maximum economic growth. Furthermore, the current policy of matching should be removed to allow the optimal production/innovation decisions to be made by firms. If this is done the government may be able to offset the negative effects of over-taxation.

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List of Appendices

Appendix I: Derivation of the theoretical growth model
Appendix II: Derivation of the OLS estimation equations for the production function
Including:
1) OLS output for equations (6.2), (6.2a), and (6.4)
2) Figure 3-- Plot of squared errors vs. the natural log of output (heteroskedasticity test)
3) Figure 4-- Observations used for capital stock
4) Figure 5-- ADF test of stationarity for equation (6.4) data

Appendix III: Theoretical estimates of the optimal rates of taxation and growth
Appendix IV: Derivation of the OLS estimation equations for TFP
Including:
1) OLS output for equation (7.3) (a preliminary attempt not mentioned in the body of the paper)
2) Figure 6-- ARCH heteroskedasticity test for (7.3)
3) OLS output for equation (7.4) (the "best" model)
4) BLS data on multifactor productivity
5) Figure 7-- plot of the OLS results for (7.4)
6) Figure 8-- serial correlation test results for (7.4)
7) Figure 9-- plot of squared error vs. natural log of MFP
8) Figure 10-- ARCH heteroskedasticity test for (7.4)

Notation used in microTSP OLS output:

LNY = natural log of GDP
LNL = natural log of total hours of labor worked
LNK = natural log of the stock times capacity utilization rate
LNNON = natural log of government capital
LNDOD = natural log of government purchase for national defense
T1 = LNNON - LNY
T2 = LNDOD - LNY
PC = LNK - LNL
D( ) = the first difference of given variable = growth rate of given variable
C = constant term
t = deterministic time trend
wage = real wage
cu = capacity utilization rate
( )pc = given variable as a ratio of capital
LRi(-x) = growth rate of i = ((A)cademic, (C)ompany, (N)on-military, (D)oD) lagged x times

Appendix I

Abstract

This Appendix will outline the mathematical derivation of my theoretical model.

The Theoretical Model:

Assumptions:

1) The consumer's utility maximization problem is given as a constant elasticity function of consumption over time. Following the standard form:

$$\max \int_0^\infty \left[\left(c^{1-\theta} - 1\right) / (1-\theta)\right] \cdot e^{-\rho t}$$

Where c is consumption, $\theta > 0$ is the constant rate of intertemporal substitution, $\rho > 0$ is the constant rate of time preference, and t is time. Notice the consumer has no choice between labor and leisure (work effort is taken as given).

2) Also in the standard form, I will assume that the economy is closed, growth is positive, utility is bounded, and people are infinitely lived or intergenerational benevolent transfer exists.

3) I alter the constraint as Barro (1990). In the case of Barro's government spending model the marginal product of capital ($\partial Y/\partial k$) must be multiplied by one minus the tax rate. The tax adjustment takes place because people do not take the benefits of the taxes into consideration when choosing optimal consumption. The same thought process occurs in my model and the constraint is:

$$s.t.: \partial K/\partial t = Y(1-\tau_1-\tau_2) - c - \delta K$$

Where Y is output, K is capital, δ is the depreciation rate, and $\partial K/\partial t$ is capital stock growth rate over time. In addition, $\tau_1$and τ_2 are the ratios of non-military government spending to output and military spending to output (G_1/Y and G_2/Y respectively).

4) Each type of expenditure $G_1$and G $_2$are financed by a flat rate tax:

$$\begin{aligned} G_1 &= \tau_1 Y \\ G_2 &= \tau_2 Y \end{aligned}$$

5) The production function will be similar to Barro's model, but I break down government spending into two categories: Military and non-Military. (Which will be referred to from now on as G_1 and G_2.) Specifically, the production function takes on the following form:

$$Y = AL^{1-\alpha}K^{\alpha}\left[(G_1)^{\eta}(G_2)^{1-\eta}\right]^{1-\alpha} \text{ where k=K/L} \tag{5.1}$$

Where α is the capital share and η is the substitution rate of G_1 to G_2. This function is constant returns to scale in terms of per capita capital and total government spending. Additionally, this is a household production function with the subscripts dropped for notational simplicity.

The Solution:

The problem in solved in the normal fashion. First taking the Hamiltonian (λ is a constant multiplier):

$$H = \left[\left(c^{1-\theta} - 1\right)/(1-\theta)\right] + \lambda\left[Y(1-\tau_1-\tau_2) - c - \delta K\right]$$

where:

$$\partial H/\partial c = c^{-\theta} - \lambda = 0$$

Then, the time derivative is:

$$(\partial c/\partial t)/c = (-1/\theta)\cdot((\partial\lambda/\partial t)/\lambda)$$

Next compute the Euler equations:

$$\begin{aligned} \partial\lambda/\partial t &= \rho\lambda - \left[(\partial Y/\partial k)(1-\tau_1-\tau_2) - \delta\right]\cdot\lambda \\ ((\partial\lambda/\partial t)/\lambda) &= \rho - \left[(\partial Y/\partial k)(1-\tau_1-\tau_2) - \delta\right] \end{aligned}$$

Combining the Euler and time derivative of $\partial H/\partial c$ gives the growth rate of the economy:

$$\gamma = (\partial c/\partial t)/c = (1/\theta) \cdot [(\partial Y/\partial k)(1 - \tau_1 - \tau_2) - \delta - \rho]$$

The next step is to determine $(\partial Y/\partial k)(1 - \tau_1 - \tau_2)$. To do this the production function must be converted into tax rate form, or simply multiply and divide the left hand side by $Y^{1-\alpha}$.

$$Y = ALk^{\alpha}\left[(G_1/Y)^{\eta} \cdot (G_2/Y)^{1-\eta}\right]^{1-\alpha} \cdot Y^{1-\alpha}$$

Solving for Y then gives:

$$\begin{aligned} Y &= (AL)^{1/\alpha} k \left[\tau_1^{\eta} \cdot \tau_2^{1-\eta}\right]^{(1-\alpha)/\alpha} \; \textit{where } (\tau_1 + \tau_2) = (G_1/Y + G_2/Y) \quad (5.1a) \\ Y^{1-\alpha} &= (AL)^{(1-\alpha)/\alpha} k^{1-\alpha} \left[\tau_1^{\eta} \cdot \tau_2^{1-\eta}\right]^{(1-\alpha)^2/\alpha} \text{(This equation will be used below)} \end{aligned}$$

To find the after-tax marginal product of capital, $(\partial Y/\partial k)(1 - \tau_1 - \tau_2)$, take the partial derivative of Y with respect to k. This is modified from Barro to be:

$$\begin{aligned} (\partial Y/\partial k)(1 - \tau_1 - \tau_2) &= r + \delta \\ &= (1 - \tau_1 - \tau_2)\alpha Ak^{\alpha-1}\left[(G_1)^{\eta}(G_2)^{1-\eta}\right]^{1-\alpha} \end{aligned}$$

Multiply and divide the left hand side by $Y^{1-\alpha}$as done above. Then, substitute in the expression for $Y^{1-\alpha}$ derived above. This yields:

$$\begin{aligned} r + \delta &= (1 - \tau_1 - \tau_2)\alpha Ak^{\alpha-1}\left[(\tau_1)^{\eta}(\tau_2)^{1-\eta}\right]^{1-\alpha} \cdot (AL)^{(1-\alpha)/\alpha} k^{1-\alpha}\left[\tau_1^{\eta} \cdot \tau_2^{1-\eta}\right]^{(1-\alpha)^2/\alpha} \\ r + \delta &= (1 - \tau_1 - \tau_2)\alpha A^{1/\alpha}L^{(1-\alpha)/\alpha}\left[(\tau_1)^{\eta}(\tau_2)^{1-\eta}\right]^{(1-\alpha)/\alpha} \end{aligned}$$

Substituting this into the growth equation attained earlier gives:

$$\gamma = (\partial c/\partial t)/c = (1/\theta)\cdot\left[\left((1 - \tau_1 - \tau_2)\alpha A^{1/\alpha}L^{(1-\alpha)/\alpha}\left[(\tau_1)^{\eta}(\tau_2)^{1-\eta}\right]^{(1-\alpha)/\alpha}\right) - \delta - \rho\right] \quad (5.2)$$

To solve for the optimal ratios of government spending to output, $\tau_1$and τ_2, take the partial derivatives of the growth function with respect to each of those variables respectively.

$$\begin{aligned}
\partial\gamma/\partial\tau_1 &= \frac{\partial}{\partial\tau_1}\left(\frac{1}{\theta}\left[(1-\tau_1-\tau_2)\,\alpha A^{\frac{1}{\alpha}}L^{\frac{1-\alpha}{\alpha}}\left[\tau_1^{\eta}\tau_2^{1-\eta}\right]^{\frac{1-\alpha}{\alpha}}-\delta-\rho\right]\right)\\
&= 1/\theta\left(-\alpha A^{\frac{1}{\alpha}}L^{-\frac{-1+\alpha}{\alpha}}\left[\tau_1^{\eta}\tau_2^{1-\eta}\right]^{-\frac{-1+\alpha}{\alpha}}\right)\\
&\quad +1/\theta\left((1-\tau_1-\tau_2)\,A^{\frac{1}{\alpha}}L^{-\frac{-1+\alpha}{\alpha}}\left[\tau_1^{\eta}\tau_2^{1-\eta}\right]^{-\frac{-1+\alpha}{\alpha}}(1-\alpha)\frac{\eta}{\tau_1}\right)\\
&= 0
\end{aligned}$$

Solutions are : $\left\{\tau_2 = -\frac{-\tau_1\alpha+\eta-\eta\alpha-\tau_1\eta+\tau_1\alpha\eta}{-\eta+\eta\alpha}\right\}$,and $\left\{\tau_1 = -\frac{\eta-\eta\alpha-\eta\tau_2+\eta\tau_2\alpha}{-\eta+\eta\alpha-\alpha}\right\}$

Likewise:

$$\begin{aligned}
\partial\gamma/\partial\tau_2 &= \frac{\partial}{\partial\tau_2}\left(\frac{1}{\theta}\left[(1-\tau_1-\tau_2)\,\alpha A^{\frac{1}{\alpha}}L^{\frac{1-\alpha}{\alpha}}\left[\tau_1^{\eta}\tau_2^{1-\eta}\right]^{\frac{1-\alpha}{\alpha}}-\delta-\rho\right]\right)\\
&= 1/\theta\left(-\alpha A^{\frac{1}{\alpha}}L^{-\frac{-1+\alpha}{\alpha}}\left[\tau_1^{\eta}\tau_2^{1-\eta}\right]^{-\frac{-1+\alpha}{\alpha}}\right)\\
&\quad +1/\theta\left((1-\tau_1-\tau_2)\,A^{\frac{1}{\alpha}}L^{-\frac{-1+\alpha}{\alpha}}\left[\tau_1^{\eta}\tau_2^{1-\eta}\right]^{-\frac{-1+\alpha}{\alpha}}(1-\alpha)\frac{1-\eta}{\tau_2}\right)\\
&= 0
\end{aligned}$$

Solutions are : $\left\{\tau_2 = -\frac{-1+\eta+\alpha-\eta\alpha+\tau_1-\tau_1\eta-\tau_1\alpha+\tau_1\alpha\eta}{1-\eta+\eta\alpha}\right\}$,and $\left\{\tau_1 = -\frac{-1+\alpha+\eta-\eta\alpha+\tau_2-\eta\tau_2+\eta\tau_2\alpha}{1-\alpha-\eta+\eta\alpha}\right\}$

To find the optimal ratios, combine the solutions for $\partial\gamma/\partial\tau_1 = 0$ and $\partial\gamma/\partial\tau_2 = 0$. The optimal ratio for military spending to total output is given by:

$$\frac{-1+\alpha+\eta-\eta\alpha+\tau_2-\eta\tau_2+\eta\tau_2\alpha}{1-\alpha-\eta+\eta\alpha} = \frac{\eta-\eta\alpha-\eta\tau_2+\eta\tau_2\alpha}{-\eta+\eta\alpha-\alpha}$$

$$\tau_2 = 1-\alpha-\eta-\eta\alpha = (1-\eta)(1-\alpha) \tag{5.2b}$$

Likewise the solution for τ_1 is:

$$\frac{-1+\eta+\alpha-\eta\alpha+\tau_1-\tau_1\eta-\tau_1\alpha+\tau_1\alpha\eta}{1-\eta+\eta\alpha} = \frac{-\tau_1\alpha+\eta-\eta\alpha-\tau_1\eta+\tau_1\alpha\eta}{-\eta+\eta\alpha}$$

$$\tau_1 = -\eta(-1+\alpha) = \eta(1-\alpha) \tag{5.2a}$$

The optimal values of $\tau_1$and τ_2 agree with the optimal tax rate derived by Barro. In his simple government spending model with constant returns to scale, he finds that the optimal tax rate is 1-α. (Where α is the capital share of productivity and 1-α is the government share.) My results simply find the same thing to apply when the government share is slightly more complex.

Finally, the condition positive growth is:

$$\delta + \rho < \alpha^2 A^{\frac{1}{\alpha}} L^{-\frac{-1+\alpha}{\alpha}} \left[(-1)^{-\eta} \eta^{\eta} (-1+\alpha)(-1+\eta)^{1-\eta}\right]^{-\frac{-1+\alpha}{\alpha}}$$

And the condition for bounded utility is:

$$\rho > \alpha^2 A^{\frac{1}{\alpha}} L^{-\frac{-1+\alpha}{\alpha}} (1-\theta) \left[(-1)^{-\eta} \eta^{\eta} (-1+\alpha)(-1+\eta)^{1-\eta}\right]^{-\frac{-1+\alpha}{\alpha}}$$

which must hold if $\rho > 0$, $A > 0$, and $\theta \geq 1$.

APPENDIX II

This appendix outlines the mathematical derivation of the production function. These equations will then be estimated using ordinary least squares.

The economic model is created by performing a logarithmic transformation of the production function:

$$\begin{aligned} Y &= AL^{1-\alpha}K^{\alpha}\left[(G_1)^{\eta}\cdot(G_2)^{1-\eta}\right]^{1-\alpha} \\ \ln Y &= \ln A + (1-\alpha)\ln L + \alpha\ln K + (1-\alpha)\,\eta\ln G_1 + (1-\alpha)\,(1-\eta)\ln G_2 \end{aligned}$$

Now using the form similar to Aschauer (1989), I will assume that the data contains a deterministic time trend. Also, I will add an independent and identically distributed error term. Then, I rename the coefficients in the following manner:

$$\ln Y_t = \beta_0 + \beta_1\ln L_t + \beta_2\ln K_t + \beta_3\ln G_{1t} + \beta_4\ln G_{2t} + \beta_5 t + e_t \qquad (6.1)$$

Unfortunately, this equation cannot be estimated directly because the data is nonstationary. Because "macro-variables" are highly dependent on time, I must take the first differences:

$$\begin{aligned} \ln Y_t - \ln Y_{t-1} &= \beta_0 - \beta_0 + \beta_1\left[\ln L_t - \ln L_{t-1}\right] + \beta_2\left[\ln K_t - \ln K_{t-1}\right] + \beta_3\left[\ln G_{1t} - \ln G_{1t-1}\right] \\ &\quad + \beta_4\left[\ln G_{2t} - \ln G_{2t-1}\right] + \beta_5\left[t - t - 1\right] + \left[e_t - e_{t-1}\right] \end{aligned}$$

In this case the first difference will be equal to the growth rate, but more importantly the coefficients will maintain the same value as in the original specification. After simplifying the above equation, the final model becomes:

$$\Delta\ln Y_t = \beta_5 + \beta_1\Delta\ln L_t + \beta_2\Delta\ln K_t + \beta_3\Delta\ln G_{1t} + \beta_4\Delta\ln G_{2t} + \nu_t \qquad (6.2)$$

Intuitively, β_0 is the time trend coefficient; β_2 should equal 1-α; β_3 should equal α, or the capital share; β_4 should equal $(1-\alpha)\,\eta$ or $\tau_1$at the optimal; and β_5 should equal $(1-\alpha)\,(1-\eta)$or τ_2 at the optimal; and $\nu_t = e_t - e_{t-1}$ and is the new i.i.d. error term. In order to ensure that ν_t is i.i.d., e_t must be a random walk. (Note: in the actual analysis the level of capital stock will be multiplied by the capacity utilization rate. This is done to account for the partial use of the capital stock in a given period. However, this will not change the mathematical derivation.)

The second possible why to estimate the production function is by using the tax ratio form:

$$Y = (AL)^{1/\alpha} k \left[\tau_1^{\eta} \cdot \tau_2^{1-\eta}\right]^{(1-\alpha)/\alpha} \quad \text{where } k = K/L$$

Then, the log transformation takes the following form:

$$\ln Y = 1/\alpha \ln A + 1/\alpha \ln L + \ln k + [(1-\alpha)/\alpha]\, \eta \ln \tau_1 + [(1-\alpha)/\alpha]\,(1-\eta) \ln \tau_2$$

The estimation equation specification will maintain the same form as above:

$$\ln Y = \mu_1 + \mu_2 \ln L + \mu_3 \ln k + \mu_4 \ln \tau_1 + \mu_5 \ln \tau_2 + \mu_6 t + e$$

Once again, I must take the first differences to compensate for the non-stationary data. This will yield a equation similar to the first specification:

$$\Delta \ln Y_t = \mu_0 + \mu_2 \Delta \ln L_t + \mu_3 \Delta \ln k_t + \mu_4 \Delta \ln \tau_{1t} + \mu_5 \Delta \ln \tau_{2t} + \varepsilon_t \quad (6.2a)$$

As in the first specification, the estimation coefficients will retain the same intuitive values: μ_0 is the time trend coefficient; μ_2 should equal $1/\alpha$; μ_3 should equal 1; μ_4 should equal $[(1-\alpha)/\alpha]\,\eta$ or $\tau_1$at the optimal; and μ_5 should equal $[(1-\alpha)/\alpha]\,(1-\eta)$or τ_2 at the optimal; and ε_t is the error term.

The final way to obtain logical estimate for the production function is by changing its entire structure. In other words, I alter the model so that constant returns to scale exist for all three inputs. I do this using the exact procedure as Aschauer (1989). More specifically the production function is rewritten as:

$$Y = AL^{1-\alpha-\beta-\gamma} K^{\alpha} G_1^{\beta} G_2^{\gamma} \quad (6.3)$$

In this case, the nonstationary data can be assumed stationary after dividing both sides by K. *This* transformation yields:

$$Y/K = A\,(L/K)^{1-\alpha-\beta-\gamma}\,(G_1/K)^{\beta}\,(G_2/K)^{\gamma}$$

Then, after the log transformation and other explanatory variables are added, the following model is created:

$$(\ln Y - \ln K)_t = \theta_1 + \theta_2 (\ln L - \ln K)_t + \theta_3 (\ln G_1 - \ln K)_t + \theta_4 (\ln G_2 - \ln K)_t$$

$$+\theta_5 wage_t + \theta_6 cu + \theta_7 t + e_t \tag{6.4}$$

The interpretation of the regression coefficients is altered only slightly. $\theta_1$will represent lnA; θ_2 should equal $(1 - \alpha - \beta - \gamma)$; θ_3 should equal β; θ_4 should equal γ; θ_5 will represent the worker quality effects; θ_6 is the effect of capacity utilization; θ_7 will represent the time trend effects; and e_t is the error term.

The rest of Appendix II contains results of the regressions run on the equations specified above. Note: all data specifications are listed in the body of this paper.

(6.2)

LS // Dependent Variable is D(LNY)
Date: 8-01-1995 / Time: 17:13
SMPL range: 1968 - 1993
Number of observations: 26

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	0.0112014	0.0023665	4.7332332	0.0001
D(LNL)	0.6203803	0.2921326	2.1236258	0.0457
D(LNK)	0.2166451	0.1220436	1.7751451	0.0904
D(LNNON)	0.0072548	0.0300733	0.2412360	0.8117
D(LNDOD)	-0.0384362	0.0354973	-1.0827913	0.2912

R-squared	0.867141	Mean of dependent var	0.024881
Adjusted R-squared	0.841835	S.D. of dependent var	0.021596
S.E. of regression	0.008589	Sum of squared resid	0.001549
Log likelihood	89.57385	F-statistic	34.26567
Durbin-Watson stat	2.377824	Prob(F-statistic)	0.000000

(6.2a) TAX RATIO FORM

LS // Dependent Variable is D(LNY)
Date: 8-01-1995 / Time: 17:08
SMPL range: 1968 - 1993
Number of observations: 26

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	0.0106128	0.0022644	4.6868431	0.0001
D(LNL)	0.8011981	0.1718713	4.6616176	0.0001
D(PC)	0.1893081	0.1175512	1.6104307	0.1222
D(T1)	-0.0079755	0.0286167	-0.2787001	0.7832
D(T2)	-0.0574464	0.0323825	-1.7739977	0.0906

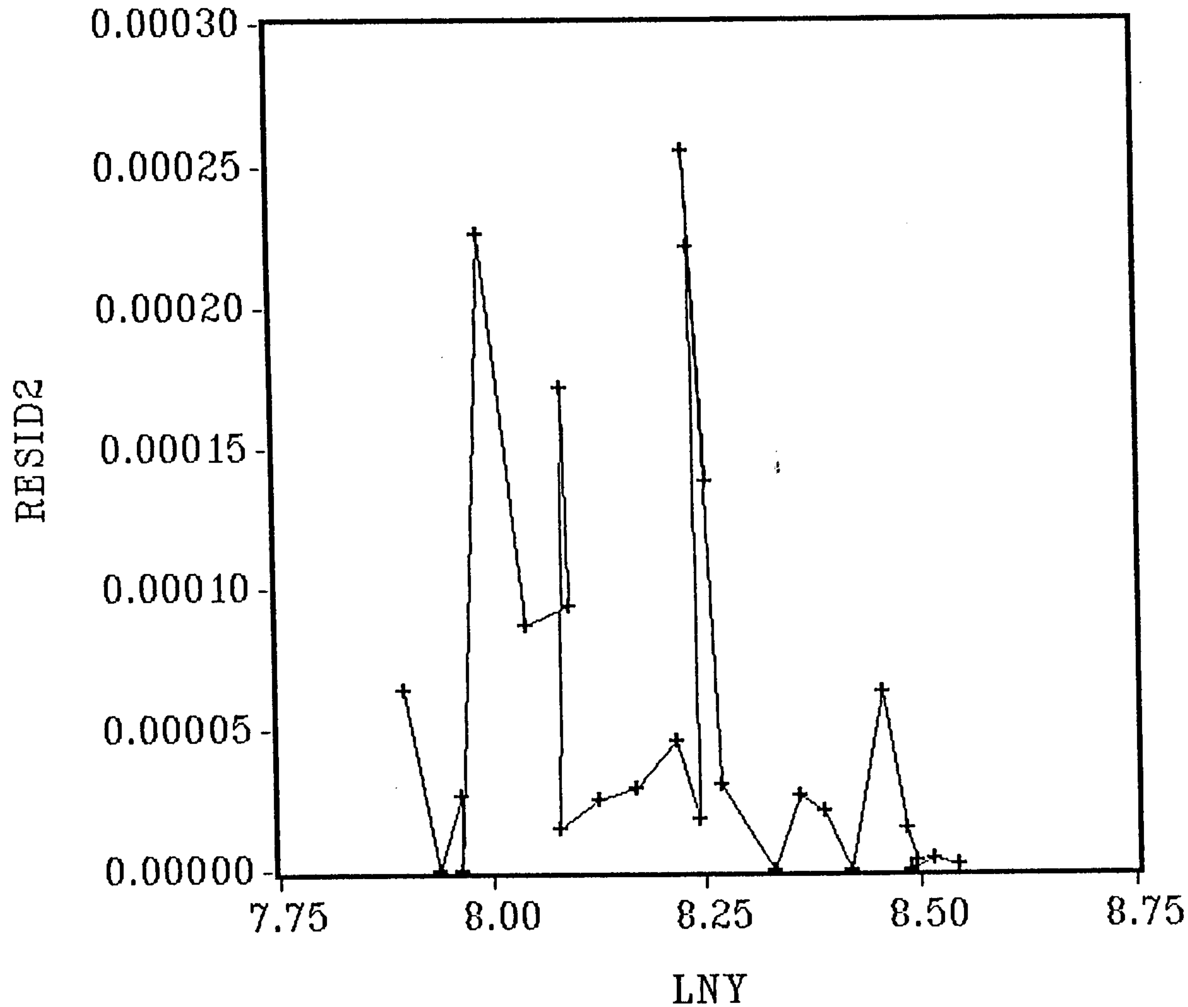
R-squared	0.879588	Mean of dependent var	0.024881
Adjusted R-squared	0.856652	S.D. of dependent var	0.021596
S.E. of regression	0.008177	Sum of squared resid	0.001404
Log likelihood	90.85261	F-statistic	38.35027
Durbin-Watson stat	2.261303	Prob(F-statistic)	0.000000

(6.4)

LS // Dependent Variable is YPC
Date: 8-01-1995 / Time: 16:54
SMPL range: 1967 - 1993
Number of observations: 27

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	-8.8981283	1.0656010	-8.3503378	0.0000
LPC	0.8055702	0.0931708	8.6461612	0.0000
NONPC	0.0691145	0.0293038	2.3585523	0.0281
DODPC	-0.0116127	0.0205114	-0.5661571	0.5773
T	0.0091278	0.0009269	9.8473757	0.0000
WAGE	0.1322163	0.1410836	0.9371485	0.3593

R-squared	0.873274	Mean of dependent var	-0.032594
Adjusted R-squared	0.843101	S.D. of dependent var	0.021757
S.E. of regression	0.008618	Sum of squared resid	0.001560
Log likelihood	93.43620	F-statistic	28.94240
Durbin-Watson stat	1.267336	Prob(F-statistic)	0.000000


0.00030
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
RESID2
7.75
8.00
8.25
8.50
8.75
LNY

obs	STOCK				
1965			3287.680	3397.251	3507.314
1970	3628.572	3737.662	3836.854	3946.390	4089.247
1975	4220.427	4304.777	4391.966	4508.066	4664.120
1980	4843.204	5001.920	5163.010	5281.268	5360.511
1985	5499.632	5654.399	5772.459	5875.459	5996.538
1990	6104.464	6206.935	6264.029	6313.905	

FIGURE 5

Augmented Dickey-Fuller: UROOT(T,1) YPC

Dickey-Fuller t-statistic		-4.6491
MacKinnon critical values:	1%	-4.3738
	5%	-3.6027
	10%	-3.2367

Augmented Dickey-Fuller: UROOT(T,1) LPC

Dickey-Fuller t-statistic		-6.5559
MacKinnon critical values:	1%	-4.3738
	5%	-3.6027
	10%	-3.2367

Augmented Dickey-Fuller: UROOT(T,1) NONPC

Dickey-Fuller t-statistic		-2.8708
MacKinnon critical values:	1%	-4.3738
	5%	-3.6027
	10%	-3.2367

Augmented Dickey-Fuller: UROOT(T,1) DODPC

Dickey-Fuller t-statistic		-2.4511
MacKinnon critical values:	1%	-4.3738
	5%	-3.6027
	10%	-3.2367

APPENDIX III.

This appendix will summarize the results of the empirical test of the theoretical model described in Appendix I.

Remember that the growth equation is:

$$\gamma = \frac{1}{\theta}\left[(1-\tau_1-\tau_2)\,\alpha A^{\frac{1}{\alpha}} L^{\frac{1-\alpha}{\alpha}}\left[\tau_1^{\eta}\tau_2^{1-\eta}\right]^{\frac{1-\alpha}{\alpha}} - \delta - \rho\right] \tag{5.1}$$

In order to estimate the growth equation and optimal ratios, I will use the following parameters:

$$\begin{bmatrix} \theta = 1.00 \\ \alpha = 0.4 \\ \rho = 0.02 \\ \delta = 0.0 \\ A = 1.58 \\ L = 1.00 \end{bmatrix}$$

Since the empirical analysis could not reveal an accurate estimate of η, I will use the 1993 values of $\tau_1$and τ_2 to proxy the optimal values. Using these two equations, I sloved for the actual value of the constant of government substituition. In 1993 the parameters had the following values:

$$\begin{aligned} G_1/Y &= \tau_1 = 0.0256 \\ G_2/Y &= \tau_2 = 0.0476 \end{aligned}$$

If the government was performing growth maximizing behavior, then according to these values, it should enact a flat rate income tax of 7.2%. Clearly this is a much smaller rate than is currently being enforced. Despite this inconsistency between theory and reality, from these values I can still extract a value for the constant of government substitution.

Remember the optimal tax rates are:

$$\begin{aligned} \tau_1 &= \eta\,(1-\alpha) \\ \tau_2 &= (1-\alpha)\,(1-\eta) \end{aligned}$$

Combing these equations with the actual values and solving for η gives:

$$\eta = .35$$

Using this value as a proxy for the optimal amount, I can now calculate the growth maximizing tax rates and the overall optimal growth rate. *First*, if $\eta = .35$ is used along with the real life capital value share, $\alpha = 0.4$, then the optimal tax rates would be:

$$\begin{aligned}\tau_1 &= \eta (1-\alpha) = .21 \\ \tau_2 &= (1-\alpha)(1-\eta) = .39\end{aligned}$$

Likewise, using all of the parameters specified above the theoretical optimal growth rate is:

$$\begin{aligned}\gamma &= \frac{1}{\theta}\left[(1-\tau_1-\tau_2)\,\alpha A^{\frac{1}{\alpha}} L^{\frac{1-\alpha}{\alpha}} \left[\tau_1^{\eta}\tau_2^{1-\eta}\right]^{\frac{1-\alpha}{\alpha}} - \delta - \rho\right] \\ &= 6.8353 \times 10^{-2}\end{aligned}$$

Of course this value does not carry much weight in real life. (Unfortunately, theory and reality do not always correspond –see the regression results in Appendix II.) The real productivity of the government sector does not match up with the theoretical value. The actual real life value of η is 0.35; however, this would require enforcing an α value of 0.9. Therefore, the growth rate would still not equal the level above.

The two important points to realize are: 1) the the actual level of taxation in society is larger than the government's share of production, and 2) although the overall estimate is inaccurate, the theory is still an accurate portrayal of the trade-off's involved with government and growth.

APPENDIX IV.

This appendix will outline the mathematical derivation of the TFP growth rate. This equation will then be estimate using OLS.

The next step is to determine the total factor productivity growth rate. Barro and Martin (1995) give the following as the general form for calculating TFP growth rate (which is consistent with Griliches 1973):

$$\begin{aligned} \ln(A_{t+1}/A_t) &= \ln(Y_{t+1}/Y_t) - (1-\alpha_t)\ln(L_{t+1}/L_t) - \alpha_t \ln(K_{t+1}/K_t) \\ \text{where } \alpha_t &= (\alpha_{t+1} + \alpha_t)/2 \end{aligned}$$

Expanding this to fit my model, the TFP growth rate is:

$$\begin{aligned} \ln(A_{t+1}/A_t) &= \ln(Y_{t+1}/Y_t) - (1-\alpha)\ln(L_{t+1}/L_t) - \alpha\ln(K_{t+1}/K_t) \\ &\quad - (1-\alpha)\,\eta\ln\left(G_{1_{t+1}}/G_{1_t}\right) - (1-\alpha)(1-\eta)\ln\left(G_{2_{t+1}}/G_{2_t}\right) \end{aligned}$$

Or rewritten in simpler form:

$$\begin{aligned} \Delta\ln(A_t) &= [\Delta\ln Y_t] - (1-\alpha)[\Delta\ln L_t] - \alpha[\Delta\ln K_t] \\ &\quad - (1-\alpha)\,\eta[\Delta\ln(G_{1t})] - (1-\alpha)(1-\eta)\left[\Delta\ln G_{2_{t+1}}\right] \end{aligned} \tag{7.1}$$

(Where the coefficients α and η are assumed to be constant over time and are taken from the OLS estimates of equation 6.2, seen in Table i and in Appendix II.) After the TFP growth rate estimates are calculated, they are regressed against the various types of R&D efforts. Specifically, I will be regressing the growth rates of federally funded military R&D, non-military federally funded R&D, company funded R&D, and non-federally funded academic R&D on TFP growth. The general estimation equation is:

$$\Delta\ln(A_t) = \lambda_0 + \lambda_1[\Delta\ln Academic_t] + \lambda_2[\Delta\ln Company_t] + \lambda_3[\Delta\ln NoN_t]$$

$$+\lambda_4[\Delta\ln DoD_t] + \lambda_5[wage_t] + \lambda_6[cu_t] + \varepsilon_t \tag{7.2}$$

This equation was estimated using several different lag structures (reference the body of the paper section VII to find the best model and my reasoning). The results for my most preferred specification are included in this appendix.

7.3

LS // Dependent Variable is TFP
Date: 8-03-1995 / Time: 14:52
SMPL range: 1976 - 1993
Number of observations: 18

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	0.3474637	0.1781080	1.9508596	0.0869
LRA(-5)	0.0318858	0.0506007	0.6301458	0.5462
LRA(-6)	-0.1331507	0.1016564	-1.3098118	0.2266
LRC(-4)	0.0425262	0.0834989	0.5093023	0.6243
LRC(-5)	0.1516951	0.0485306	3.1257589	0.0141
LRN(-6)	-0.0096383	0.0315872	-0.3051320	0.7681
LRN(-7)	0.0039492	0.0263249	0.1500162	0.8845
LRD(-7)	-0.0059989	0.0522681	-0.1147717	0.9115
LRD(-8)	0.0551959	0.0288166	1.9154204	0.0918
CU(-1)	-0.0776835	0.0402160	-1.9316578	0.0895

R-squared	0.744228	Mean of dependent var	0.010835
Adjusted R-squared	0.456485	S.D. of dependent var	0.005895
S.E. of regression	0.004346	Sum of squared resid	0.000151
Log likelihood	79.65143	F-statistic	2.586430
Durbin-Watson stat	2.105970	Prob(F-statistic)	0.097751

FIGURE 6

ARCH Test: 1 lags

F-statistic	0.83105	Probability	0.3764
Obs*R-Squared	0.89241	Probability	0.3448

ARCH Test: 2 lags

F-statistic	0.54649	Probability	0.5917
Obs*R-Squared	1.24088	Probability	0.5377

ARCH Test: 5 lags

F-statistic	0.33140	Probability	0.8789
Obs*R-Squared	2.48826	Probability	0.7783

ARCH Test: 4 lags

F-statistic	0.49573	Probability	0.7398
Obs*R-Squared	2.52763	Probability	0.6397

(7.4)

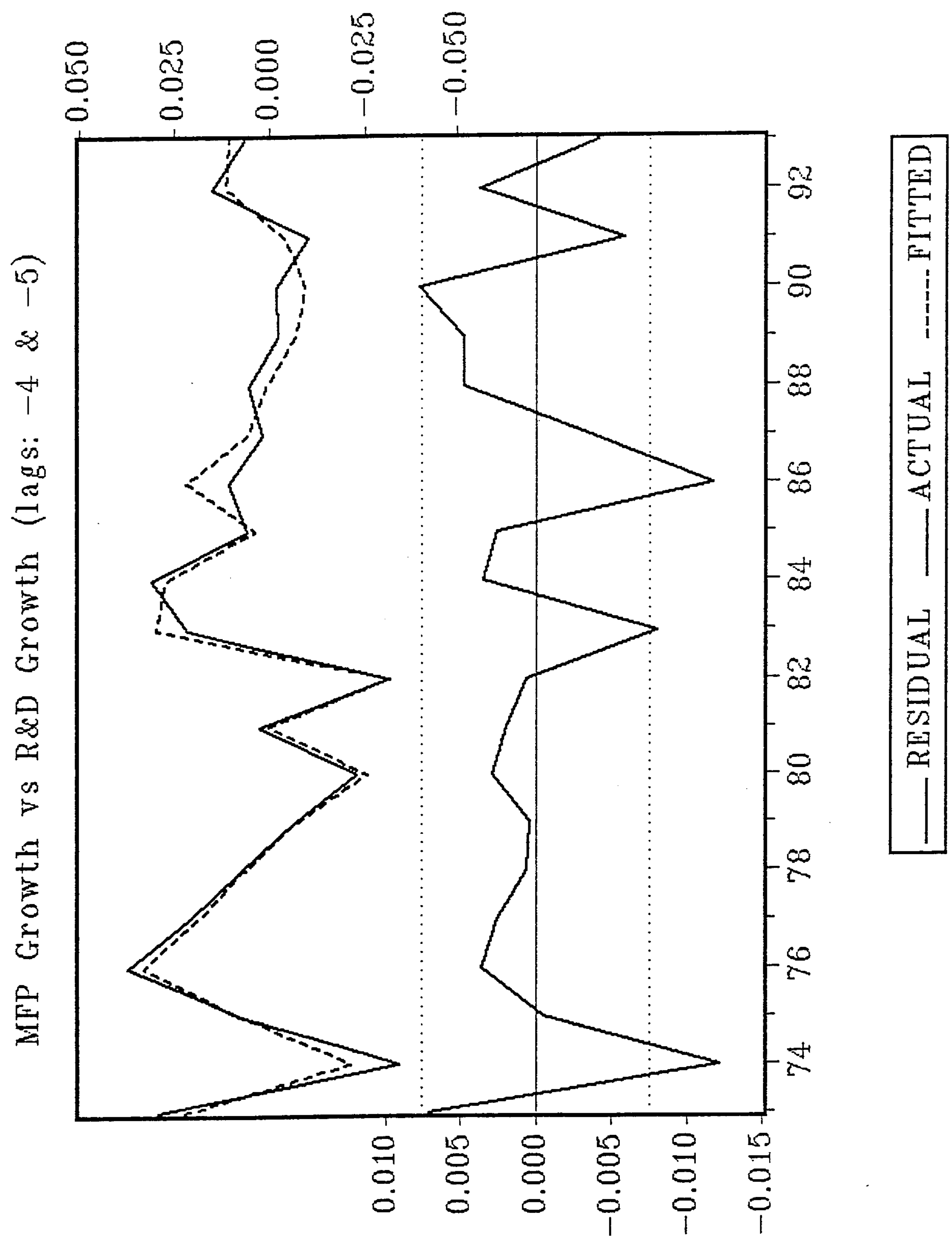
LS // Dependent Variable is LRM
Date: 8-03-1995 / Time: 11:45
SMPL range: 1973 - 1993
Number of observations: 21

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	1.0287020	0.2460554	4.1807745	0.0015
LRA(-4)	-0.6514490	0.1154293	-5.6437064	0.0002
LRA(-5)	0.2925784	0.0887458	3.2968152	0.0071
LRC(-4)	-0.2324308	0.0670637	-3.4658208	0.0053
LRC(-5)	0.0609508	0.0532551	1.1445070	0.2767
LRN(-4)	-0.1164505	0.0344913	-3.3762312	0.0062
LRN(-5)	0.0711712	0.0342833	2.0759692	0.0621
LRD(-4)	0.0810704	0.0419952	1.9304717	0.0797
LRD(-5)	0.1236782	0.0587644	2.1046427	0.0591
CU(-1)	-0.2285189	0.0553425	-4.1291718	0.0017

R-squared	0.911463	Mean of dependent var	0.004206
Adjusted R-squared	0.839023	S.D. of dependent var	0.018886
S.E. of regression	0.007577	Sum of squared resid	0.000632
Log likelihood	79.52658	F-statistic	12.58236
Durbin-Watson stat	2.258788	Prob(F-statistic)	0.000134

obs	MULTI				
1965			2928.939	3006.301	2997.661
1970	2988.652	3085.358	3173.453	3267.958	3157.270
1975	3179.784	3299.458	3369.667	3393.496	3369.405
1980	3292.471	3299.772	3197.051	3266.742	3368.793
1985	3387.444	3423.015	3428.424	3446.299	3437.270
1990	3429.911	3394.427	3445.228	3466.494	

FIGURE 7



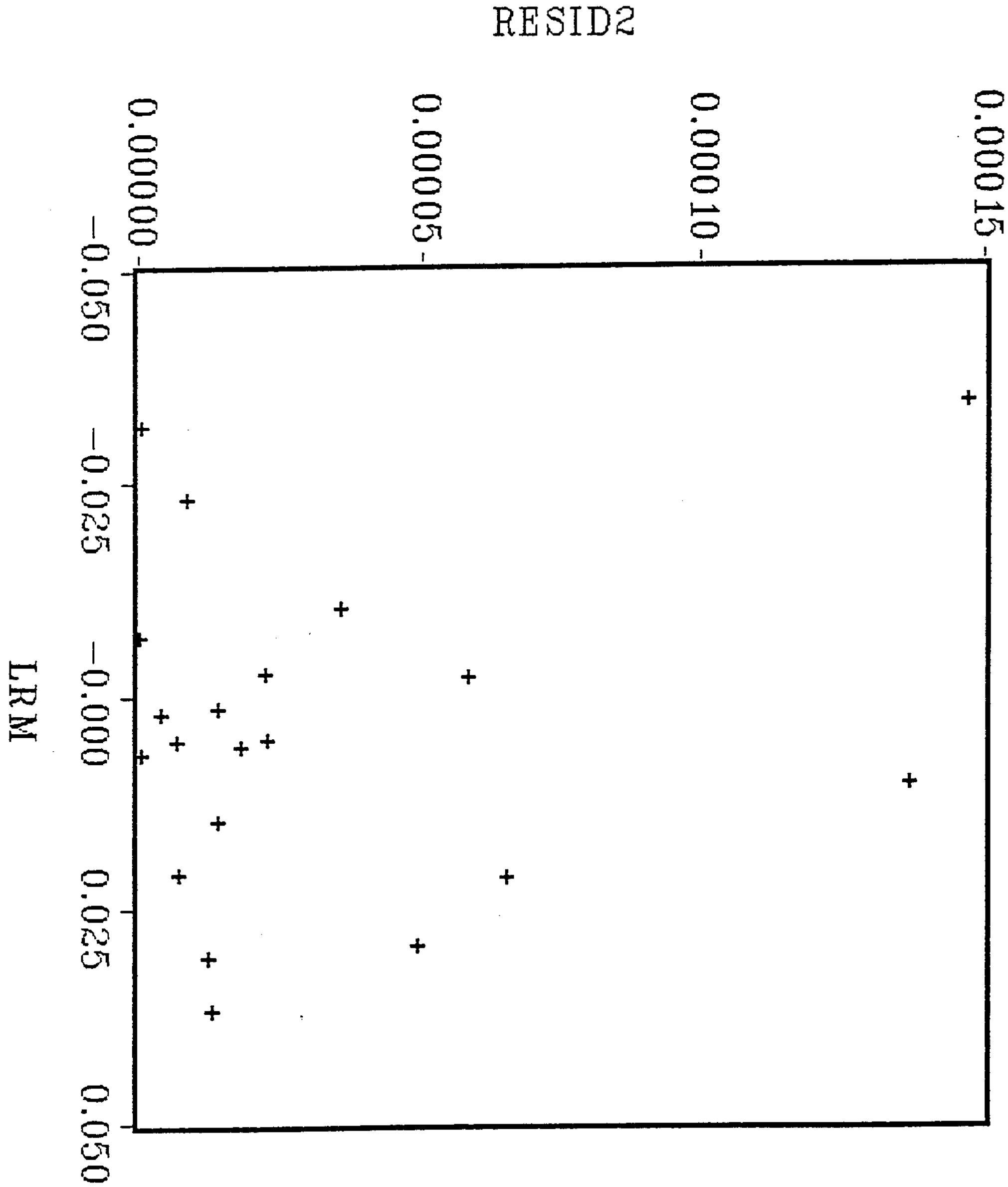
MFP Growth vs R&D Growth (lags: -4 & -5)
0.050
0.025
0.000
-0.025
-0.050
0.010
0.005
0.000
-0.005
-0.010
-0.015
74
76
78
80
82
84
86
88
90
92
RESIDUAL
ACTUAL
FITTED

FIGURE 8

Serial Correlation LM Test: 5 lags

F-statistic	0.45487	Probability	0.7975
Obs*R-Squared	5.77225	Probability	0.3290

FIGURE 9



RESID2
0.00000
0.00005
0.00010
0.00015
LRM
−0.050
−0.025
−0.000
0.025
0.050

FIGURE 10

ARCH Test: 2 lags

F-statistic	0.33432	Probability	0.7207
Obs*R-Squared	0.76215	Probability	0.6831

ARCH Test: 3 lags

F-statistic	0.16006	Probability	0.9214
Obs*R-Squared	0.59691	Probability	0.8971

ARCH Test: 4 lags

F-statistic	0.10042	Probability	0.9802
Obs*R-Squared	0.55063	Probability	0.9684

ARCH Test: 5 lags

F-statistic	0.32320	Probability	0.8878
Obs*R-Squared	2.22592	Probability	0.8171