Implications of the New Growth Theory to Agricultural Trade Research and Trade Policy

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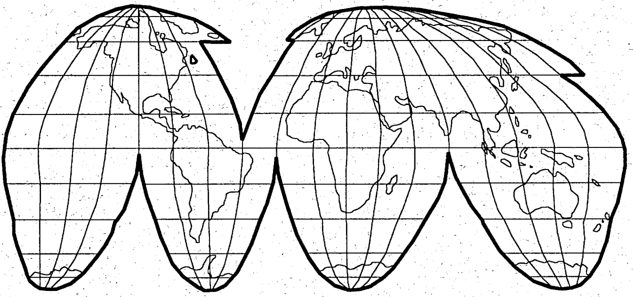

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A Dynamic CGE Model of R&D Based Growth in the U.S. Economy: An Experiment Using the New Growth Theory

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Abstract

An empirical multi-sector general equilibrium model is developed drawing largely from the R&D-based endogenous growth theory of Romer (1990) and Grossman and Helpman (1992). Results suggest that trade policies affect growth, but in the absence of international technical spillovers, such effects are relatively small. R&D promoting policies induce private agents to allocate more resources to R&D activities, which increase technological spillovers and the production of capital variety. The financial cost of the policies evaluated range from 1.3 to 2.7 percent of household income. The corresponding gains in social welfare are relatively large.

Key words: Dynamic Applied General Equilibrium, Endogenous Growth, Trade

I. Introduction

A variety of empirical evidence indicates that national growth rates are correlated with many economic, social and political variables, including many that are affected by government policies. These observations on the disparity in growth rates among the world's economies led to the formulation of models in which per capita income grows indefinitely and long-run performance depends upon structural and policy parameters of the domestic and global economy. One strand of theory views capital accumulation, broadly defined to include human capital, as the driving force behind economic growth (Jones and Manuelli, 1990, King and Rebelo, 1993, and Rebelo, 1991). A second approach casts external economies in a leading role in the growth process. Each firm's investment in either physical (Arrow, 1962) or human capital (Lucas, 1988) inadvertently contributes to the productivity of capital held by others. The third approach, pioneered by Romer (1990), Grossman and Helpman (1991) focuses on the evolution and adoption of new technology. They develop analytical models wherein technological innovation leads to the production of capital of different varieties and spillovers of technical know-how are the engine of growth.

Empirical evidence in support of intra- and inter- sectoral spillovers reported in several firm and industry level studies is compelling (e.g., Mansfield, 1983, and Bernstein and Nadiri, 1988, among others). Bernstein and Nadiri, for instance, report intra-sectoral rates of return to own R&D expenditure in five manufacturing industries that range from 12 percent to 24 percent, and corresponding inter-sectoral rates of return ranging from 16 to 45 percent. Several studies searching for spillovers have also been conducted at the national and cross-national level. Nonneman and Vanhoudt (1996) added capital variety to the extended Solow model fit to data by

Mankiw, Romer and Weil (1992) and found that the resulting model provided a good explanation of growth in OECD countries. Still others suggest that product and process innovations and learning by doing are not the sole sources of economic growth. For example, Stiglitz (1996) in his review of the growth experience of East Asian countries, suggests that the determinants of growth are caused by a host of market failures that vary by country and level of development. Keeping in mind the gulf that still appears to exist between the various theories of growth and the lack of case studies and broader based econometric evidence to support one category of theory over another, it is nevertheless insightful to empirically explore the effects of technological spillovers and the production of capital variety on growth using a more detailed empirical model in the Romer and Grossman and Helpman tradition. In this context, attention can be focused on the extent to which a decentralized market economy provides adequate incentive for the accumulation of production technology, and how variations in economic structures, institutions and policies might translate into different rates of productivity gain.

In this paper we specify an empirical R&D based growth model whose analytical antecedents draw upon Romer (1990) and Grossman and Helpman (1991). Their models tend to depict economies in more aggregated terms, and focus on the steady state growth path. In contrast, the model developed here is calibrated to fairly desegregate U.S. data of the social accounting matrix variety, and solved for both the out-of-steady state and the steady state paths of the endogenous variables. Differentiated capital increases in variety with technological progress, and each capital variety is associated with a patent or blueprint. Patents are in turn produced by R&D activities. Technological spillovers occur in R&D activities as the result of knowledge accumulation. Firms in the differentiated capital producing sector behave as monopolists and earn rents from blueprints or patents to which they own the copyrights. Consequently, as in its antecedents, the model entails two market failures, spillovers in the production of blueprints, and imperfect competition in the production of differentiated capital.

Relative to its analytical counterpart, the empirical model permits disaggregation of the economy into several sectors and allows us to investigate the magnitude to which government policy affects sectoral production, private R&D activities, capital accumulation, economic growth and welfare in a manner consistent with theory, and to assess whether these magnitudes are within a range that is roughly consistent with economic history.

Limitations in data, however, condition the analysis of the growth effects of government policies. For example, no data series are available on the domestic production and flows of technical know-how and the extent of spillovers. In practice, the international transmission of knowledge cannot easily be separated from international exchange of goods and services. Hence, we have to ignore the international exchange of technical information, and assume that the stock of technical knowledge accumulates only by the country's own R&D activities. Lack of R&D data for aggregate industries is another limitation. Furthermore, in Grossman and Helpman's (1994: 31) words, "what generally gets recorded as R&D represents only a portion of the resources that firms spend on learning to produce new goods or with new methods", and thus, we need to rely on calibration methods to obtain the necessary benchmark for these variables.

Given the mentioned analytical, empirical and data limitations, this paper should be viewed as an experimental step to explore the properties of an empirical endogenous growth model of the U.S. economy whose analytical underpinnings are the R&D based growth models of Romer and Grossman and Helpman. Thus, the ongoing analysis illustrates the nature of insights that can be obtained from an empirical application of a particular strand of the new growth theory, recognizing that there are almost surely other sources of economic growth that are not captured by this model.

The remainder of the paper is organized as follows. In section II we present the model structure. Section III reports and analyzes results from policy simulations. Major findings are that while trade policies have some effects on growth, they tend to be small. However, R&D subsidies can have sizable impacts on the growth of the U.S. economy.

II. The Model Structure

The economy is presumed to have no effect on prices for final goods in world markets (but the domestic prices of final goods are endogenously determined), and its R&D activities are assumed to not influence the rate of accumulation of knowledge capital in the world at large. This construction allows us to study the channels through which world markets influence domestic behavior without being concerned about feedback relationships on growth from the rest of the world (Grossman and Helpman, 1992: 144).

II.1. The final output production sectors

The model distinguishes four final output production sectors: (1) agriculture and food processing, (2) mineral and materials, (3) manufacturing, and (4) services. With a constant returns to scale technology, each sector produces a single output using inputs of two non-augmented factors, labor (L) and conventional capital (B), one augmented factor and a set of intermediate goods. The augmented factor is a set of differentiated capital where an element of the set denotes a particular variety of capital. Factors of production are perfectly mobile in the economy, but immobile internationally. Firms producing final outputs face perfect competition in both output and input markets. The value added function for a representative firm in each of the four sectors is of Cobb-Douglas form, while the intensities of intermediate inputs are fixed.

Outputs of four sectors are demanded in several different ways. They serve as intermediate inputs in the production processes; they meet final demand of households, government and foreigners; and they are employed to produce differentiated capital variety. Exports of each domestically produced good are derived from a constant elasticity of transformation function (a CET function), while domestic demand for the domestic good can be imperfectly substituted by a foreign good through Armington system.

II.2. The R&D sector

In real economies, research and development activities and the production of technical innovations are often carried out by firms engaged in the production of goods or intermediate factors. In the model, for the purpose of simplification, private R&D activity is separated from other production activities and aggregated into an independent sector, which we define as an R&D sector[1].

R&D activities are often categorized as product and process innovations. Yet, the R&D product itself may be intangible and/or be embodied in a service or intermediate factor of production. In the model, the output of the R&D sector is "technological knowledge", defined as the number of blueprints -- technical patents produced. This output, in turn, is a requirement permitting the production of new types of differentiated capital. R&D technology is presumed to be of Cobb-Douglas form, with the two primary factors (L and B), and the pool of common

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[1] Since the market for the outputs of R&D activities is assumed to be perfectly competitive, R&D activities can be viewed either as a separate sector or as activities performed by the sector producing capital variety.

technological knowledge that has accumulated over time from past production activities. From the individual firm perspective, this technology exhibits constant returns to scale in its employment of the two primary factors. The key difference from production activities in other sectors is that the cumulative output of each individual firm's R&D activities expands the common pool of technological knowledge to the R&D sector. These technological spillovers are a positive externality which increases the productivity of the two primary factors employed by each firm engaged in the R&D production. Consequently, spillovers are a source of technological progress which increases the efficiency of producing additional blueprints. The blueprints enable the accumulation of differentiated capital and sustain the long-run growth of the economy.

II.3. Differentiated capital and its production

Growth is traditionally associated with capital accumulation (Krugman, 1994, Young, 1995, and World Bank, 1993). However, "if life consisted of nothing more than adding homogeneous capital to a homogeneous production process", it would be hard to observe any remarkable growth such as East Asia's success (Stiglitz, 1996). In the current model capital accumulation is modeled as the increase in the number of differentiated capital, $k(i)$, where i is the index for one type of capital variety. With a constant elasticity of substitution, various capital varieties imperfectly substitute for each other in final good production. The total number of capital varieties are equal to the numbers of blueprints available in the economy. Hence, $i \in \{1, M_t\}$, where M_t is the number of blueprints produced over the interval from period 1 to t. When the number of blueprints increases, the number of capital varieties also increase and, hence, capital accumulation occurs.

Before a capital variety can be produced, investors must obtain a new blueprint or patent by purchasing it from the R&D sector. Once obtained, a property right to the knowledge embodied therein is presumed to lie with the producer of the capital variety pertaining to this particular patent. This right prevents others from producing an identical variety of capital and, consequently, ensures its producer monopolistic rents in the capital variety market. If the property right cannot be enforced, then other firms would compete away the monopoly rents accruing to the patent, leaving investors with no incentive to purchase a patent, nor for its suppliers to incur the cost of its production. Thus, monopolistic power is derived from the firm's rights to a patent which permits it to charge a capital rental price above the marginal product of the capital variety it sells to producers of final goods.

Firms in the capital good sector have forward-looking behavior, that is, they make an investment decision to buy a new blueprint and to produce a new capital variety so as to maximize the long-run expected returns from an infinite stream of monopoly revenues. The expected returns from an investment must be comparable with those from holding a 'safe' asset such as bonds or bank deposits. Thus, asset market equilibrium requires that for any firm operating in the differentiated capital production sector, at any time period, the following non-arbitrage condition must hold:

$$P_{k(i)}k(i) + \Delta V(i) = r\,V(i)$$

where $P_{k(i)}$ is monopoly capital rental price for $k(i)$, and hence, $P_{k(i)}k(i)$ is the revenue of a monopoly firm i in one time period, $V(i)$ is the value of the firm i, and r is the interest rate on the safe asset. $\Delta V(i)$ denotes change in the value of firm i with respect to time. In equilibrium, the value of the firm is equal to its aggregate investment expenditures, which include the cost of a new blueprint purchased from the R&D sector ($P_{R\&D}$), plus the cost of final goods employed in the production of a particular variety of capital ($MC_{k(i)}k(i)$). Imposition of a transversality condition to rule out speculative bubbles gives:

$$V_t(i) \;=\; \Sigma_{t=0}^{\infty} R(t)\,[P_{k(i)_t} k_t(i)]\,.$$

That is, the value of the firm is equal to the discounted value of the stream of monopoly revenues, where R(t) is a discount factor defined according to

$$R(t) \;=\; \Pi_{s=0}^{t}(1 + r_s)^{-1}\,.$$

We assume that all differentiated capital goods are produced from forgone outputs according to an identical constant-returns-to-scale Cobb-Douglas production function. Consequently, all produced capital goods bear the same rental price, and final good producers employ equal quantities *k(i) = k* of each. Given the identical Cobb-Douglas technology, demand for final goods as inputs to produce a capital variety has fixed shares in value terms. Thus, the marginal and average cost of capital good production caused by employing the forgone outputs is the same for each producer of differentiated capital, and is determined from the individual good prices according to:

$$MC_k \;=\; \Pi_{j=1}(P_j/\eta_j)^{\eta_j}$$

where MC_k is the marginal and average cost of each capital variety produced, P_j is the price of good j employed in the capital production, j = 1, 2, .., 4, η_j is the expenditure shares of that good.

Since all monopoly firms face the same prices of the forgone outputs, the same cost of a new blueprint, and the same quantity demanded by the final output producers, each firms charges the same mark-up rental rate, $P_{k(i)} = P_k$, such that $P_k = rMC_k/\alpha_3$, where α_3 is the substitution elasticity of demand among different capital varieties for the final good producers.

II.4. The household

Households own the primary factors and the equity of monopoly firms. The representative household chooses aggregate consumption and savings to maximize an intertemporal utility:

$$\Sigma_{t=0}^{\infty}(1+\rho)^{-t}\frac{TC_t^{1-\sigma}-1}{1-\sigma}$$

subject to its budget constraint:

$$SAV_t = W_{L_t}L_t + W_{B_t}B_t + P_{k_t}(M_t k_t) - PC_t TC_t + TR_t$$

where ρ is the rate of time preference, σ is the inverse of the intertemporal elasticity of substitution, TC_t is an index of overall consumption, PC_t is the price index for consumption, SAV_t is household savings, $W_{L,t}$ and $W_{B,t}$ are unit price for the primary factor L and B, respectively, M_t is the number of differentiated capital, and TR_t is net government transfers. TC, in fact, is a composite of four specific goods according to fixed expenditure shares. Thus, the price of overall consumption, PC, is determined from the individual good prices, according to:

$$PC = \Pi_{j=1}(P_j/\gamma_j)^{\gamma_j}$$

where γ_j is the expenditure share of good j in overall consumption.

II.5. The government

The government has three functions in the model: collecting taxes, distributing transfers, and purchasing goods. The government is presumed to follow a balanced budgetary policy for all periods, and hence, its overall expenditure (transfer plus purchases) equals its overall income. To avoid an unbalanced government budget, when a policy experiment affects government revenues, a lump-sum household income tax/subsidy is imposed to equate government expenditures with revenues.

III. Policy analysis

We illustrate the mechanics of the model with the aid of a series of experiments addressing issues of foreign trade and R&D promotion. The data on U.S. foreign trade reveal a tariff rate of 19 percent for agriculture, and zero for services. To clarify the growth effects of different policies, we first solve the model with all tariffs removed, and denote the resulting transition path as the "base-run" against which the growth effects of other presumed policy interventions are compared. Results are reported for both the steady state and transitional equilibria. The transitional dynamics are derived from the time discrete model over an interval of 200 years, with the equilibria spaced one year apart.

III.1. Effects of tariffs on growth

First, we simulate import tariff policies by choosing ad valorem import tariff rates of 30 percent, imposed first on the agricultural and food processing sector, and then on the manufacturing sector. Imposition of import tariffs in different sectors affects the growth rate differently. Protecting agriculture causes the growth rate to rise while protecting the manufacturing sector causes its to fall (Figures 1-2). These results depend critically on Stolper-Samuelson like effects on the relative rental rates of primary resources and their effect on the production of blueprints by the R&D sector.

The R&D sector is most labor intensive. Among the four final good producing sectors, agriculture is relatively capital intensive, while manufacturing is labor intensive. Imposing a specific tariff on one sector protects the sector's domestic producers from foreign competition and hence raises the sector's output. An increase in the output of the more labor (capital) intensive sector's output induces it to employ relatively more labor (capital) than capital (labor). As the R&D sector is the most labor intensive, the long run effects of a policy to protect a labor intensive final good sector (manufacturing in this case) negatively affects the production of new blueprints by bidding up the wage rate, while a policy to protect a capital intensive sector (agriculture) stimulates the production of new blueprints as wages fall.

The new blueprints produced by the R&D sector are purchased by new monopoly firms. When we observe an increase in the production of blueprints, we also observe a concomitant rise in the investment demand for new blueprints. The investment decision entails a comparison of the investment cost of purchasing a new blueprint and the infinite stream of the profits obtained from the monopoly capital rental price. Compared with the "base-run," we observe that protecting the agricultural sector causes monopoly profits to rise more than the price for the new blueprints, while protecting the manufacturing sector leads to the reversal of this result (see Figure 3). When the ratio of monopoly profits to the price of new blueprints rises, investment in blueprints is stimulated and new monopoly firms are created. Similar reasoning explains why investment demand for new blueprints falls when the manufacturing sector is protected.

As the supply of and demand for new blueprints rise, the growth rate rises. The reason is that an increase in new blueprints enlarges the pool of common technical knowledge (the public good) and hence the output of new blueprints increases steadily. As the source of growth in the model is the accumulation of R&D outputs, the growth in the economy is stimulated.

Nevertheless, the trade protection effects on growth are relatively small. Imposing a 30 percent tariff on the imports of agricultural goods, causes the long-term growth rate to rise by only 0.045 percent, while a 30 percent tariff on the imports of manufacturing goods causes the rate of growth to fall by 0.08 (Table 2, rows 1-2, column 1). These effects are small since a one percent increase from a base growth rate of 2.2 percent only reduces the time required for the country to double its income by less than a single year.

Such small growth effects mainly arise because tariffs have a relatively small effect on relative factor prices. We observe that imposing a 30 percent tariff on agricultural goods causes the ratio of the prices for the two primary factors, i.e., W_B/W_L, to rise by only 0.22 percent, while imposing a 30 percent tariff on manufacturing imports causes W_B/W_L to fall by 0.57 percent.

The small growth effect of trade policies stands in stark contrast with other empirical evidence. For example, Levine and Renelt (1992) use a panel data set for a large number of countries and find the ratio of exports to GDP to be a robust predictor of economic growth; and Gopinath, Kennedy and Roe (1995) report that economic growth is positively correlated with the share of foreign trade in GDP. Our model does not take into account the growth effects from technological spillovers that might result from foreign trade in differentiated capital and blueprints. Thus, in light of other empirical evidence, we are left to conjecture that, at least for economies which are relatively more dependent on R&D activities in other countries, the effect on R&D production from trade protection is likely to be swamped by the growth effects from international technological spillovers that seem to occur when an economy is opened to world markets.

III.2. Effects of tariffs on transition paths

Next, we turn attention to the transition paths to the new steady state. Interestingly, 90 percent of the resource adjustment occurs in the initial year. After the first year, resource reallocation continues, but the magnitude is small (Table 3, rows 12-14). In contrast to the "base-run", agricultural output rises 4.2 percent in the first year following the imposition of a 30 percent tariff on agricultural imports, while outputs of the other three sectors fall. For example, manufacturing output falls by 1.6 percent (Table 5, row 1). If manufacturing is protected by a 30 percent tariff, its output rises by 1.1 percent in the first year, while the other three sectors experience a fall in output (Table 5, row 2). As resource adjustments are small after the first year, the difference in the sectoral growth rates along their transitional paths to the steady state is also very small.

Irrespective of which final sector is protected by tariffs, more labor is employed in the production of blueprints in the first year, but such increases are small: 0.1 percent when agriculture is protected and 2 percent when manufacturing is protected (Table 3, row 9). In the first year, the demand for capital falls by 0.2 percent when agriculture is protected but rises by 2.6 percent when manufacturing is protected (Table 3, row 10). These first year adjustments cause R&D output to rise in both cases and to rise the most when the manufacturing sector is protected (output of the R&D rises by 0.1 and 1 percent, respectively, in these two cases). However, these first year increases in R&D output cannot support long-term growth as the final sectors compete for economy-wide resources over the remainder of the path to the steady state. As we discussed above, when a final good labor-intensive sector is protected by a tariff, it will tend to bid away labor from the R&D sector. We observe that after a few periods, labor departs the R&D sector when manufacturing is protected, while labor moves into R&D over the entire path when agricultural is protected. In contrast to the first year's adjustment, labor employed in R&D increases by 1 percent in the new steady state when agriculture is protected, and falls by 2 percent when manufacturing is protected.

In a static model, trade protection policy usually lowers total welfare due to dead-weight losses. We observe that since the increase in the growth rate as a result of protecting agriculture is small, the instantaneous felicity falls below the base run along the transition path and only begins to rise when the path closely approaches the steady state. The dynamic measure of equivalent variation presented in Mercenier (1995, (see Appendix for the formula) shows a slight welfare loss of 0.01 percent when agriculture is protected (Table 2, row 2, column 3)[2]. Of course since protecting manufacturing lowered growth, welfare falls throughout the transition to the steady state (the measure of welfare equivalent variation fall by 3 percent, see Table 2, row 3, column 3).

III.3. R&D Promoting policies stimulate growth

In the context of this model, technical knowledge has two properties. It is "non-rival" in the sense that its use by one does not preclude its use by others, and it is "partially excludable" in the sense that a producer of differential capital obtains the property right to a blueprint at a

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[2] This measure is sensitive to the time-discount rate in the intertemporal utility function and substitution elasticities between importable and domestic goods.

cost that is less than its true marginal value in the following sense. While another producer of differentiated capital cannot appropriate the blueprint due to the property right, the blueprint nevertheless represents an increase in the stock of knowledge which leads, incrementally, to the more efficient production of blueprints. However, the initial purchaser of the blue print is unable to appropriate these additional returns to knowledge that the blueprint embodies. Consequently, the initial purchaser is only willing to pay a price which reflects the blueprint's value in its production, i.e., a price that is lower than the patent's true marginal value when account is taken of the value of its contribution to the stock of knowledge that is available to all in the production of additional blueprints. The second market failure is more conventional; imperfect competition in the production of differentiated capital tends to lower the scale of the output of each variety of capital. In the absence of public intervention, these market failures are likely to induce agents to under-invest in the provision and acquisition of new technologies. The correction of these failures can, in principle, lead to Pareto superior outcomes.

Many governments pursue various forms of support for education and R&D activities. The U.S. provides tax incentives for private R&D investments and supports public investment through the National Science Foundation and a number of other agencies[3]. To explore the basic mechanism of these policies, we investigate two policy instruments each of which promote growth by encouraging private R&D activity. One instrument is an ad valorem cost subsidy to producers of R&D outputs (blueprints), and the other is an ad valorem rental price subsidy to the employers of differentiated capital. A subsidy to producers of R&D output encourages them to

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[3] However, according to the National Science Foundation (1995), the share of federally funded R&D in total industrial R&D expenditures has declined from 40 percent in 1953 to under 18 percent in 1995. Since 1989, real federally funded R&D expenditures declined by an averaged rate of 3.0 percent per year.

bid primary resources away from other sectors. The second policy is based on the consideration that employers of differentiated capital pay a rental price that exceeds its marginal product. A subsidy to the employers of differentiated capital increases its demand, thereby providing incentives to increase the production of differentiated capital due to rising rents, which in turn increases the number of new producers of differentiated capital and the production of blueprints.

A 10 percent subsidy is chosen for each of the policies. A lump-sum household income tax is imposed simultaneously to assure that the government's budget is balanced. In the case of the R&D subsidy, the lump-sum tax is equivalent to 1.3 percent of total household income, and accounts for 2.7 percent of household income in the case of the differentiated capital user's subsidy. A 10 percent R&D subsidy causes the growth rate to rise from a base rate of 2.2 percent to 2.5 percent per annum in the steady state (Table 2, row 5), an increase of about 12 percent. The base growth rate of 2.2 percent, if sustained, implies that US real income will double in about 32 years. A rate of 2.5 percent implies a doubling of real income in about 28 years.

Interestingly, in the case of the second instrument, the 10 percent subsidy to the employers of differentiated capital yields almost the same increase in the rate of growth which, as we show later, implies the two instruments have almost the same effects on the production of R&D output in the two new steady states. However, their transition paths vary as they cause quite different resource adjustment among sectors. Welfare gains from either policy are relatively large and roughly comparable. We focus on the more detailed effects of these policies in the following two subsections.

Adjustments Induced by Subsidizing the Cost of R&D Production

The R&D production cost-subsidy induces a relatively large reallocation of primary resources, the major adjustment of which mostly occur in the first few years (Table 4, rows 9-10, column 1). In the first year, labor and capital employed by the R&D sector increase by 11 and 13 percent, respectively. After the first year's adjustment, inputs used by the R&D sector continue to increase along the transition path. However, contrasting the new steady state to the first years adjustment, the additional increase in input levels amounts to only about 1 percent. R&D output increases corresponding to the increase in the input levels.

When the R&D production cost is reduced by the subsidy, the price for its output, new blueprints, falls (see Table 4, row 1). A lower blueprint price provides incentives for new monopoly firms to enter the capital production sector. This can be seen from the results reported in Table 4, rows 2 - 4. We observe that although the monopoly rental price of each capital variety and hence monopoly profits fall by 1.6 percent initially following the R&D subsidy, the profit relative to the cost of purchasing a new blueprints rises by 8.5 percent in the same year (year 1). The relative increase (not absolute increase) in monopoly profits provides incentive for investors to increase the number of new monopoly firms and the production of capital variety.

Why does the monopoly rental price, and hence profits per firm fall in the initial period? (Table 4, rows 2-3) The monopoly rental price is positively affected by the two factors: the marginal cost of capital production and the interest rate (see Appendix, Equation (A5)). Final goods are employed in the production of differentiated capital. With the exception of the manufactured good, the R&D subsidy causes the final good prices to fall (for reasons discussed later), and thus a slight decline in the marginal cost of differentiated capital production. The interest rate also falls in the first year. These two factors cause the monopoly rental price and hence monopoly profits per firm to fall initially. Consequently, the monopoly firms which invested in the production of capital variety before the shock suffer a fall in rents. Later, with the gradual rise of the interest rate, the monopoly rental price rises. Monopoly profits per firm fall along the entire transition path as the result of a decline in the demand for each variety (which results from a rise in the price of differentiated capital), and the increase in the number of varieties of capital. However, the increase in the number of capital varieties exceeds the fall in profits per firm so that the sum of monopoly profits of all firms in the capital variety sector increase.

Changes in the prices and quantities of final goods along their transition paths differ from those in the steady state, and especially so in the initial year. While the large increase in the employment of labor and capital in the R&D sector increases R&D output instantaneously, time is required for differentiated capital to accumulate. An increase in the accumulation of differentiated capital is required to “compensate” the final goods sectors "loss" of the primary resources that are reallocated to R&D production. Consequently, the outputs of some final goods must fall in the first few years following the R&D subsidy.

Household behavior evolves as follows. Changes in consumption and savings reflect the outcome of inter temporal decision over the entire time path. Moreover, behavior is constrained in each period by the requirement that domestic market prices adjust to equalize the value of total demand to the value of total supply. This implies that the household’s response to an unanticipated shock that can increase future welfare is to, incrementally, forgo consumption and increase its saving rate initially. Consequently, we observe that household savings rise throughout the time path, while household consumption falls in the first year and then rises along the transition path. However, the adjustment in consumption undershoots its “base-run” path until period 21 (Figure 4).

The growth in savings, and hence in investment, cause investment demand for final goods to rise throughout adjustment to the new steady state. Since the share of manufacturing goods employed in the production of differentiated capital is relatively large (76 percent), investment generates additional derived demand which accounts for more than 18 percent of total demand for this good, while the total derived demand for other final goods is less than one percent. Consequently, only the demand for manufacturing is strongly influenced by the investment demand, while changes in the demand for the other three goods mainly reflect consumption demand. Thus, in the first few years, and especially in the first year, the markets for manufactured goods clear at a higher price and quantity while the markets for agriculture and other final goods clear at lower prices and quantities.

In the long-run, increases in R&D output enlarges the pool of common knowledge (an argument factor in the R&D production function). Effectively, knowledge "spillovers" increase, which increases the productivity of the primary factors employed in R&D production, and thus the output of blueprints rises steadily along the transition and the steady state paths. Concomitant with the increase in the production of blueprints is the increase in capital variety. The employment of a larger number of differentiated capital in final good production in turn increases the productivity of primary resources employed in final good production. Thus, compared with the base-run, outputs for all sectors increase after the 20-th year. In the 200-th year, when the economy closely approximates the new steady state, final good production levels are 70 percent higher than the comparable base-run levels.

Welfare gains are relatively large. The equivalent variation index in response to the 10 percent R&D subsidy registers a gain of 23 percent from the "base-run" (Table 2, row 5, column 3). Recall that a lower consumer's subjective time discount rate, ρ[4], implies that relatively higher weights are placed on future consumption. Consequently, the level of welfare gain for a relatively low discount rate is higher for any given rate of growth.

Adjustments Induced by Subsidizing Differentiated Capital used in Final Production

Similar to the R&D subsidy, subsidizing the employers of differentiated capital causes a relatively large reallocation of primary resources, and first year changes are comparable to those of the R&D policies (Table 4, rows 9-10, columns 3). However, the mechanism causing reallocation is different than the former case. In the former case, firms in the R&D sector bid primary resources away from other sectors. In the case of subsidizing the employers of differentiated capital, the direct beneficiaries are the final good producers. The subsidy to the price paid by them for differentiated capital inputs induces them to increase capital demand. However, the monopoly price is a mark-up price chosen by the monopoly firms based on the marginal cost of capital production (exclusive of the cost of new blueprints of course) and the interest rate. If these two variables remained unchanged, investors would not respond by increasing the number of new monopoly firms to produce a larger number of differentiated capital varieties.

We observe that in the first year the marginal cost of differentiated capital production to fall, a result also observed for the case of the R&D subsidy. However, in contrast to the R&D subsidy, the interest rate rises by 9 percent. The rise in the interest rate dominates the fall in the

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[4] To be consistent with the benchmark growth rate and interest rate, the time discount rate is relatively small (about one percent).

marginal cost of producing differentiated capital, thus inducing producers to raise its price. Given the subsidy to employers, the market for differentiated capital clears at a higher price to producers and a lower price to employers of differentiated capital. The rise in monopoly profits, i.e., rents to holders of blueprints, induces increases in forgone consumption and investment in new blueprints.

In other words, the rise in profits induces an increase in the number of new firms each of which produce an additional new variety of capital. Of course, this increase in demand for blueprints can only be satisfied by bidding up the price of new blueprints in order to stimulate a supply response by the R&D producers. Since primary factors are in fixed supply, their rental rates also rise.

In contrast to the base-run steady state, outputs for all sectors increase. Thus, through this process, different subsidy policies generate similar results, i.e., the R&D sector competes for more resources to increase its output, which in turn increases technological spillovers and a higher rate of economic growth, and relatively large welfare gains. The equivalent variation index records a welfare gain of 27 percent, 4 percent higher than that in the case of R&D subsidy.

IV. Conclusions

In this paper we introduce and explore the properties of an empirical endogenous growth model, the antecedents of which are the R&D based growth models of Romer (1990) and Grossman and Helpman (1992). The empirical model is specified and calibrated to U.S. data of the social accounting matrix variety. The model is solved to obtain both the transitional and steady state equilibria, using the same software used to solve static applied general equilibrium models[5]. To explore how selected economic instruments affect growth through their effects on the accumulation of technological knowledge, two groups of policies, trade policies and R&D inducing policies, are evaluated. The results suggest that tariffs to protect producers of final goods only have little effect on stimulating domestic production of new blueprints and the accompanying increase in the production of additional varieties of capital. These results appear at odds with analyses of time series cross-country data. The most likely reason for this discrepancy is that the model does not take into account technological spillovers accruing from trade, and thus suggests a direction for future research. Spillovers likely accrue from foreign trade in blueprints and intermediate capital varieties, and when they are "mixed" with domestic resources (as in reverse engineering) they lead to a more rapid advance of technological knowledge.

The R&D promoting policies considered are subsidizing the costs of R&D activities, and subsidizing the price paid by employers of differentiated capital inputs in which the new technology is embodied. Both of these policies have the effect of increasing technological spillovers which raises the productivity of resources employed in the R&D sector. The cost of these subsidies were to be covered by a lump sum tax on the household ranging from 1.3 percent to 2.7 percent of total household income. The long-run growth rises by 12 percent, or, from another perspective, the length of time for real US income to double is shortened by about 4 years (i.e., from 32 years to 28 years).

Other important insights suggested by the analysis concern how markets induce changes

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[5] Brooke et al, 1988.

in incentives affecting the level and nature of resource adjustments in various sectors of the economy; their influence on savings and investment; and the “speed”of adjustments following the imposition of a policy. As a general rule, growth promoting policies channel resources into R&D activities and into the production of differentiated capital, which in turn increased the productivity of primary resources (and the income streams from these resources) in the production of final goods.

Finally, this paper should not be regarded as an exploration of the determinants of growth in the U.S. economy per se. Instead, this research illustrates and suggests the nature of insights that can be obtained from an empirical application of a particular strand of the new growth theory, recognizing that there are likely multiple sources of economic growth. Our experimentation with the new growth theory suggests that its empirical application is only slightly more complicated than the application of traditional static computable general equilibrium modeling, and that “off the shelf software” is sufficient for its implementation.

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Appendix I: Tables

Table 1. Benchmark values for selected variables and parameters

Variables or Parameters	Values
Share parameter for differentiated capital in final production (α_3)	0.283
Price of blueprints ($P_{R\&D0}$)	30.086
Initial steady state growth rate (g_0)	0.022
Initial steady state interest rate (r_0)	0.032
Inverse of the intertemporal elasticity of substitution (σ)	1.01
Subjective time discount rate (ρ)	0.01
Monopoly profits for each firm (π_0)	0.963
Initial quantity of each capital variety (k_0)	1.343
Initial total supply of differentiated capital (M_0k_0)	1,343,273
Initial total supply of conventional capital (B_0)	896,020.6
Initial total supply of labor (L_0)	3,164,324

Table 2. Growth rate, interest rate and welfare index under different policy scenarios (%)

	Growth rate[1]	Interest rate[1]	Welfare index[2]
Base-run[3]	2.1998	3.1998	0.0
30% tariffs on agriculture	2.2008	3.2008	-0.0090
30% tariffs on manufacturing	2.1980	3.1980	-3.1320
10% R&D subsidy	2.4598	3.4649	22.6705
10% differentiated capital subsidy	2.4592	3.4644	26.6631

1. Growth rate and interest rate are at their steady state levels;
2. Welfare index is the equivalent variation defined in Appendix;
3. Base-run is the simulation in which all tariffs are eliminated.

Table 3. Effects of tariffs on some variables in the first year and the steady states[1]
(% change from the "base-run")

	30% tariffs on agriculture		30% tariffs on manufacturing	
	Year 1	Steady state	Year 1	Steady state
Price of R&D ($P_{r\&d}$)	0.4709	0.4637	3.7479	0.9267
Monopoly rental price (P_k)	0.5027	0.5520	3.9512	11.3972
Monopoly profits (π)	0.4964	0.4951	0.3250	0.8692
$\pi/P_{r\&d}$	0.0254	0.0313	-0.4800	-0.0569
Saving rate	-1.4684	0.0116	-5.8856	-0.0213
W_b/W_l[4]	0.2274	0.2223	-0.5723	-0.5603
Output price[5], Agr[6].	0.7065	0.7071	-0.2680	-0.2671
Output price, Mfc[7].	-0.0876	-0.0879	1.4338	1.4331
L[2] demanded by R&D	0.1027	0.0724	2.0518	-0.1318
B[3] demanded by R&D	-0.1733	-0.2045	2.5890	0.3757
L demanded by Agr.	4.3156	4.3062	-2.9881	-3.5161
B demanded by Agr.	4.0280	4.0177	-2.4774	-3.0257
L demanded by Mfc.	-1.5513	-1.5293	1.1146	5.9005
B demanded by Mfc.	-1.8228	-1.8017	1.6469	6.4387

1. all variables in this table are constant in the steady state;
2. L is the input factor of labor;
3. B is the input factor of the conventional capital;
4. W_b is rental rent for B and W_l is wage rate for L;
5. output prices are normalized by the current year output price index;
6. agricultural and food processing sector;
7. manufacturing sector.

Table 4. Effects of subsidy policies on some variables in the first year and the steady states[1]
(% changes from the "base-run")

	10% R&D subsidy		10% differentiated capital subsidy	
	Year 1	SS[2]	Year 1	SS
$P_{r\&d}$	-9.5466	-12.6265	0.8552	1.2005
P_k	-1.5957	8.3066	9.1621	8.2596
π	-1.5957	-5.3866	9.2842	9.5687
$\pi/P_{r\&d}$	8.4748	8.2862	8.3575	8.2689
Saving rate	4.8391	2.8505	13.0199	12.6949
W^b/W^l	-1.6744	-1.6797	-1.8209	-1.8220
Output price[3], Agr.	-0.1168	-0.1169	-0.1266	-0.1273
Output price, Mfc.	0.0780	0.0779	0.0846	0.0850
L demanded by R&D	10.7214	11.6286	11.3615	11.5879
B demanded by R&D	13.0038	13.1324	13.3911	13.6588

1. all indicators in this table are constant in the steady state;
2. the steady state;
3. output prices are normalized by the current year price index.

Table 5. Changes in the GDP and outputs under different policy scenarios (% changes from the "base-run")

		Outputs:				
		GDP	Agr.	Min.[2]	Mfc.	Ser.[3]
30% tariffs on agr.	Year 1	-0.1103	4.2063	-0.4812	-1.5872	- 0.0232
	SS[4]	0.1071	4.4080	-0.2761	-1.3655	0.1803
30% tariffs on mfc.	Year 1	-0.7582	-2.8648	-3.1700	1.1114	0.0149
	SS	-3.0506	-5.7302	-4.8606	3.3403	-2.4179
10% R&D subsidy	Year 1	0.1134	-1.8474	-1.3545	0.7241	-1.785
	SS	68.10	65.24	65.22	65.88	65.01
10% differentiated capital sub.	Year 1	0.1503	-2.1175	-1.3074	1.7510	-1.9390
	SS	75.33	71.52	72.59	76.96	71.69

1.steady state, and all variables in this table grow constantly in the steady state;
2. mineral and material sector;
3. service sector;
4. the first year which is sufficiently close to the steady state

Appendix II: The mathematical presentation of the endogenous growth CGE model

Glossary

Parameters

A_i	shift parameter in value added function
Γ_i	shift parameter in CET function
Λ_i	shift parameter in Armington function
A_k	shift parameter in differentiated capital production function
α_{1i}	share parameter for L in value added function
α_{2i}	share parameter for B in value added function
α_3	share parameter for differentiated capital in value added function
a_{ij}	input-output coefficient for i used in j
μ_i	share parameter in CET function for foreign good
υ_i	share parameter in Armington function for foreign good
θ_i	share parameter for L in R&D production function
η_i	share parameter in differentiated capital production function for good i
γ_i	share parameter in household demand function for I
ε_{mi}	elasticity of substitution in Armington function
ε_{ei}	elasticity of substitution in CET function
ρ	rate of consumer time preference
σ	inverse elasticity of intertemporal substitution in consumption

Exogenous variables

L_t	labor supply
B_t	conventional capital supply
PWM_i	world import price for good i
PWE_i	world export price for good i

Endogenous variables

PC	price index for household over all consumption
PX_i	producer price for good i
PD_i	price for good i produced and consumed domestically
PE_i	price for good i exported
PM_i	price for good i imported
P_i	price for composite good i
PVA_i	value added price for good i

P_m	price for blueprints
Mc_k	marginal cost for the production of differentiated capital
W_L	wage
W_B	rental rate for conventional capital
P_k	monopoly capital rental price
X_i	output of good i
CC_i	total absorption of composite good i
DX_i	good i produced and consumed domestically
MD_i	good i imported
EX_i	good i exported
TC	household over all consumption
C_i	household demand for composite good i
GD_i	government demand for composite good i
ID_i	investment demand for composite good i
ITD_i	intermediate demand for composite good i
Y	household income
SAV	household savings
k	one capital variety
π	monopoly profit for one firm
ΔM	new blueprints
M	the accumulated R&D outputs
r	interest rate
g	growth rate

Equations

(For all within period equations, time subscript, t, is skipped)

The final output sectors

$$X_i = \min\langle A_i L_i^{\alpha_{1_i}} B_i^{\alpha_{2_i}} \textstyle\sum_{s=1}^{t} k(s)^{\alpha_3}, a_{1i} ITD_{1i}, a_{2i} ITD_{2i}, a_{3i} ITD_{3i}, a_{4i} ITD_{4i} \rangle$$

$$\alpha_{1_i} + \alpha_{2_i} = 1 - \alpha_3, \quad \alpha_{1_i} > 0, \; \alpha_{2_i} > 0, \; \alpha_3 > 0; \quad a_{ji} > 0. \tag{A1}$$

The R&D sector

$$\Delta M = A_m L_m^{\theta} B_m^{1-\theta} M \qquad \text{(A2)}$$

$$\theta > 0$$

The differentiated capital and investment decision

$$(\Delta Mk + \Delta kM) = A_k \Pi_{i=1} ID_i^{\eta_i} \qquad \text{(A3)}$$

$$MC_k(\Delta Mk + \Delta kM) = \Sigma_{i=1} P_i ID_i \qquad \text{(A4)}$$

$$P_k = \frac{rMC_k}{\alpha_3} \qquad \text{(A5)}$$

$$\pi = (1 - \alpha_3) P_k k \qquad \text{(A6)}$$

$$(1 + r_t) P_{m_{t-1}} = \pi_t + P_{m_t} \qquad \text{(A7)}$$

The intertemporal utility, budget constraint and consumption and saving decision

$$\Sigma_{t=0}^{\infty} (1 + \rho)^{-t} \frac{TC_t^{1-\sigma} - 1}{1 - \sigma} \qquad \text{(A8)}$$

$$TC = \Pi_{i=1} C_i^{\gamma_i}, \quad 0 < \gamma_i < 1, \ \Sigma_i \gamma_i = 1,$$

$$SAV_t = W_{L_t} L_t + W_{B_t} B_t + P_k Mk + TR - PC_t TC_t \qquad \text{(A9)}$$

The CET functions and export supply

$$X_i = \Gamma_i (\mu_i EX_i^{(1+\varepsilon_{ei})/\varepsilon_{ei}} + (1 - \mu_i) DX_i^{(1+\varepsilon_{ei})/\varepsilon_{ei}})^{\varepsilon_{ei}/(1+\varepsilon_{ei})} \qquad \text{(A10)}$$

$$EX_i = (\mu_i PX_i / PE_i)^{-\varepsilon_{ei}} \Gamma_i^{-(\varepsilon_{ei}+1)} X_i \qquad \text{(A11)}$$

$$PX_i X_i = PD_i DX_i + PE_i EX_i \qquad \text{(A12)}$$

The Armingtonian functions and import demand

$$CC_i = \Lambda_i \left(\upsilon_i MD_i^{(\varepsilon_{mi}-1)/\varepsilon_{mi}} + (1-\upsilon_i) DX_i^{(\varepsilon_{mi}-1)/\varepsilon_{mi}} \right)^{\varepsilon_{mi}/(\varepsilon_{mi}-1)} \tag{A13}$$

$$MD_i = (\upsilon_i P_i / PM_i)^{\varepsilon_{mi}} \Lambda^{\varepsilon_{mi}+1} CC_i \tag{A14}$$

$$P_i CC_i = PD_i DX_i + PM_i MD_i \tag{A15}$$

Factor market equilibrium

$$\textstyle\sum_i \alpha_{1_i} PVA_i X_i + \theta P_m \Delta M = W_L L \tag{A16}$$

$$\textstyle\sum_i \alpha_{2_i} PVA_i X_i + (1-\theta) P_m \Delta M = W_B B \tag{A17}$$

$$\textstyle\sum_i \alpha_3 PVA_i X_i = P_k M k \tag{A18}$$

Commodity market equilibrium

$$CC_i = C_i + GD_i + ID_i + ITD_i \tag{A19}$$

Balanced payment condition

$$\textstyle\sum_{i=1} (PWM_i MD_i - PWE_i EX_i) = 0 \tag{A20}$$

$$SAV = \textstyle\sum_{i=1} P_i ID_i + P_m \Delta M \tag{A21}$$

Knowledge accumulation

$$M_{t+1} = \Delta M_t + M_t \tag{A22}$$

Growth rate

$$g_t = \frac{\Delta M_t}{M_t} \tag{A23}$$

steady state constraints

$$\left(\frac{1+r_{ss}}{1+\rho}\right)^{1/\sigma} = 1+g_{ss} \qquad \text{(A24)}$$

$$r_{ss} = \frac{\pi_{ss}}{P_{m_{ss}}} \qquad \text{(A25)}$$

Index of Equivalent vaiation

$$\Sigma_{t=0}^{\infty}(1+\rho)^{-1}\frac{[\hat{TC}_t(1+\phi)]^{1-\sigma}-1}{1-\sigma} = \Sigma_{t=0}^{\infty}(1+\rho)^{-1}\frac{TC_t^{1-\sigma}-1}{1-\sigma} \qquad \text{(A26)}$$

where $\hat{TC}_t$ is total consumption in "base-run". That is welfare gain resulting from the policy change is equivalent from the perspective of the representative household to increasing the reference consumption profile by ϕ percent.

Appendix III. The Data and the Calibration Strategies

The data used to create a static 1992 U.S. social accounting matrix are drawn primarily from the Global Trade Analysis Project (GTAP) data base (Hertel and Tsigas, 1995). As these are annual flow data, they must be augmented by information on capital stock, growth and interest rates. By normalizing all factor prices at unity, value of the income earned by capital provided by the GTAP database can be treated as a measure of the stock of total capital. From this stock, conventional capital (one of the primary factors of production) and differentiated capital have to be distinguished. This is accomplished using the calibration restrictions implied by the model. The average 2.2 percent per capita real GDP growth rate of the U.S. economy from 1986 - 1992 (World Bank, 1995) is chosen as the initial steady state rate of annual growth. The initial interest rate is 3.2 percent, the average rate over the same period on U.S. government long term bonds.

Calibrating the model involves selecting values for certain parameters from sources other than the primary data base, and then deriving the remaining estimates from restrictions implied by the equilibrium requirements of the model. The method used to calibrate parameters or initial values of variables associated with intra temporal economic activities are quite standard as that used in most static CGE models. We only sketch the more subtle dynamic calibration. As in static CGE models, where calibration is based on the assumption that data reflect an economy in equilibrium, we assume that the benchmark data depict a steady state growth path[6]. For simplicity, exogenous growth is ignored, and the rate of depreciation for both conventional capital and differentiated capital is assumed to be zero. To assure the existence of a balanced growth path, equality of the share parameters for the differentiated capital in the value added functions is required. Also, we assume that $\delta = \alpha_3$, where $\delta = 1-1/\varepsilon$; ε is the substitution elasticity of the demand among differentiated capital varieties. This parameter is calibrated from the existing data together with the value of the R&D output (see Appendix, Equations (A26)-(A27)). The value of R&D sector output is specified by assuming the benchmark year's stock of knowledge, M_0, to be one million and (hence, benchmark year's R&D output equals M_0 multiplied by the growth rate, g_0. Once the value of R&D output is specified, we obtain the value of differentiated capital investment by subtracting the value of R&D output from the data on total investment. The capital rental price, P_k, is a mark-up price. We normalize it to unity and derive MC_k (the unit cost of forgone output employed in capital investment) from $\alpha_3 P_{k0}/r_0 = MC_{k0}$. In the steady state, the quantity of each capital variety, k_0, is constant. Hence, k_0 can be calculated from the value of investment in differentiated capital divided by MC_{k0} and M_0, the number of new blueprints. Then, the supply of differentiated capital equals $k_0 M_0$.

The presence of an R&D sector, the output of which is difficult to measure for an actual economy, is presumed to largely be reflected in the data from the service sector. The share parameter of labor employed in R&D is chosen to be 0.9, so that the R&D sector is highly labor intensive. After these adjustments, R&D spending comprises 7 percent of sales and 12 percent of the GDP, while total investment accounts for 17 percent of GDP. The share of differentiated capital in the production of final goods is 28 percent. The initial levels of selected variables and parameters obtained from sources other than the main data base are presented in Table 1.

The equations used in the calibration are defined as follows. For clarity, we use bar to indicate parameters or benchmark values for some variables which are specified exogenously and hat to indicate benchmark variables which are given by the data from the U.S. Social Accounting Matrix. Symbols without a bar or a hat are the values calibrated.

Define

$$\hat{V} \equiv \Sigma_i PVA_i X_i + P_m \Delta M = \bar{W}_L \hat{L} + \bar{W}_B B + \bar{P}_k k \bar{M} \qquad \text{(A27)}$$

where $W_L = W_B = P_k = 1$, $B + kM$ are the value of total capital stock which can be obtained from

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[6] The steady-state assumption for the benchmark data is widely used in applied intertemporal general equilibrium models. For example, Goulder and Summers, 1989, Go, 1994, and Mercenier, 1995.

the data as their prices are normalized to unit, and, hence, $\hat{V}$ can be obtained from the data. $\Delta M = \bar{g}M$. PVA_i are calculated from

$$PVA_i = (1 - \hat{it}_i)\bar{PX}_i - \Sigma_j \hat{a}_{ji}\bar{P}_j \tag{A28}$$

and $PX_i = P_i = 1$.

From Equation (A4) and (A21), we have

$$S\hat{A}V = MC_k \Delta Mk + P_m \Delta M \tag{A29}$$

since in the steady state, $\Delta k = 0$. MC_k can be calculated after we obtain α_3 from Equation (A5).

Combining Equations (A5), (A6), (A25) and (A29) obtains

$$S\hat{A}V(1 - \alpha_3) = P_m \Delta M \tag{A30}$$

Combining Equations (A22) - (A24) and using Equation (A6) again obtain

$$\alpha_3(1 - \alpha_3)(\hat{V} - P_m \Delta M) = \bar{r} P_m \bar{M} \tag{A31}$$

Equations (A30) - (A31) are used to solved for P_m, the price for R&D output, and α_3, the share parameter for each capital variety in the final production.

Once we have α_3, k can be obtained from Equation (A4) and then we get B. The adjustment of the service is done by subtracting $P_m \Delta M$ from the original data for the value added of the service.

Figure 1 - 2: Growth rates

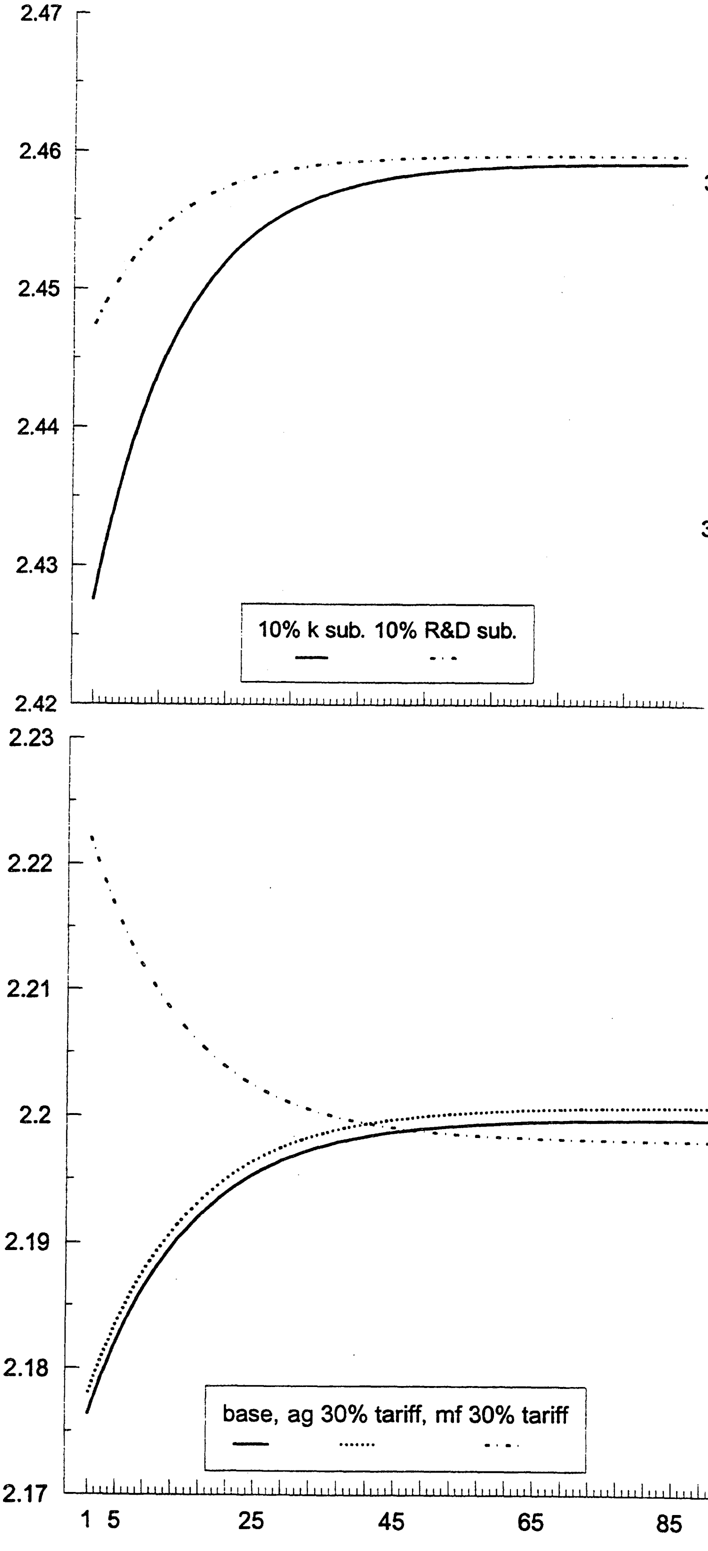
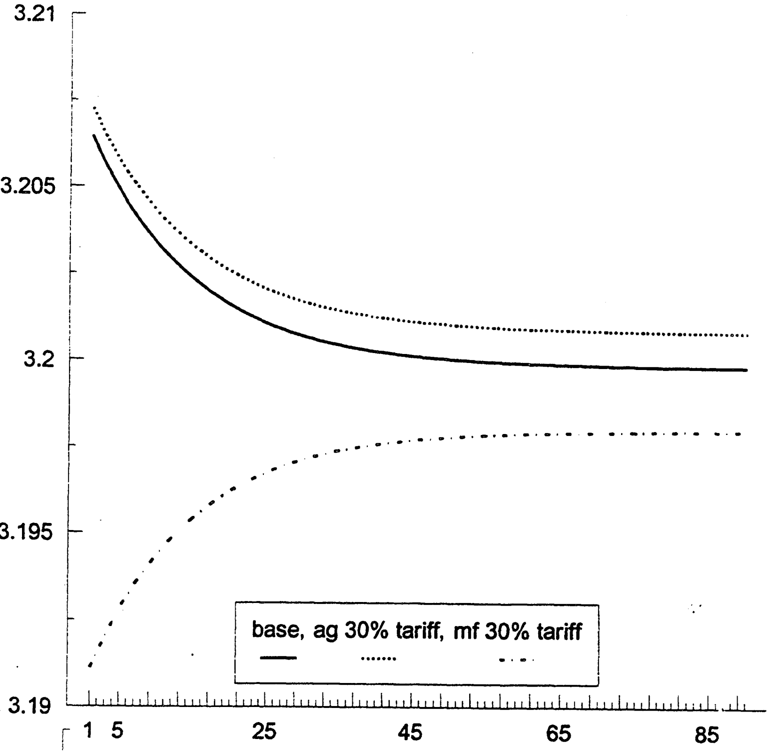


Figure 3: Ratio of profit over R&D price



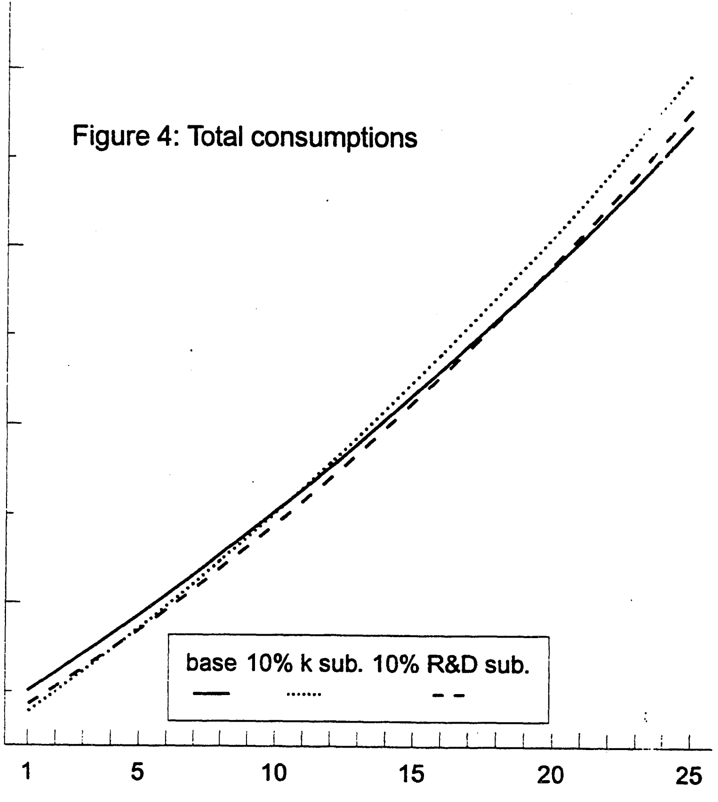


Figure 4: Total consumptions