ECONOMIC GROWTH AND GLOBAL ECONOMIC ANALYSIS:
Use Of The New Growth Theory

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Abstract

A non-technical overview of the new growth theory is provided from both an analytical and empirical perspective. Following a brief analytical sketch of the R&D based models, the results from fitting two structural models to data are presented. Results show the relative impacts on growth from trade and R&D based policies including technological spillovers from trade. The mechanism of inter-sectoral adjustments to the long-run growth path is also discussed. While the theory provides new insights into growth, some skepticism is raised as to its general applicability as an important structure in policy models. The need to apply behaviorally consistent dynamic models, e.g., of the Ramsey genre, to empirically based policy models is strongly supported.

Key Words: Endogenous Growth, Trade, Technological Spillovers

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1. Introduction

The general task of this paper is to provide a relatively non-technical discussion of the insights that the new growth theory provides into the linkages between growth and trade, our experience with calibrating this type of model to data, and some of its shortcomings and alternatives. The paper contains four major sections. Section 2 introduces the new theory by briefly discussing its analytical antecedents. Section 3 provides a non-technical overview of the Romer, (1990) (R) and the Grossman and Helpman, (1991*c*) (GH) research and development (R&D) model of growth. The model is shown to have strong implications for the role institutions and economic policy in stimulating growth.

Since the qualitative insights from theory are of limited usefulness, section 4 reports on the empirical results from calibrating an R&D-based model to the US economy, and concludes with an extension to North-South trade and growth. The latter model shows how investments in R&D in one country can spill over to another through trade alone. The concluding section suggests that while the R&D based models of endogenous growth make a strong contribution to organizing our thinking on the growth - trade process, the determinants of growth are more numerous and sector specific than is likely to be captured by a single model. [1] This is not to suggest that policy models should not model economic growth and, instead, focus on static general equilibrium albeit with specifications to capture scale economies, and other features of real economies. Indeed, it is argued in the concluding section that modeling dynamic processes, even if the source of long-run economic growth is exogenous, forces discipline on judging the degree to which a model replicates an economic process as well as lessoning the likelihood of drawing erroneous conclusions from model experiments.

2. Analytical Background

Contributions to the theory of trade and growth in 1970s extended the neoclassical growth theory of the previous decades to account for many of the static concepts found in the Heckscher-Ohlin framework. Excellent reviews of these contributions are found in Smith (1984) and Findlay (1984). Many such models drew upon the Solow-Swan framework in which saving is a constant proportion of total output. However, this leads to the inconsistency that agents optimize in choosing resources to maximize profit, but simply use a constant savings rate in choosing their consumption bundle. Drawing upon these antecedents and the earlier work of Ramsey (1928), Cass (1965) and Koopmans (1965), more recent models depict optimizing households that choose consumption and savings to maximize their "dynastic" utility, subject to an inter-temporal budget constraint in a decentralized - market economy.[2] All of these models assume that growth in total factor productivity (TFP) is exogenous.

The R&D based models of growth expand upon models of the Ramsey - Cass - Koopman's (RCK) genre by developing the mechanism where by long-run economic growth (i.e., persistence) is the outcome of the decisions of optimizing agents. Romer (1990) and Grossman and Helpman (1991c) are among the leading early contributors in this regard. The key feature is that knowledge or new ideas require resources to produce, and knowledge is treated as an *accumulable* resource that is employed in the production of *additional* knowledge. Knowledge is non-rival in the sense that use by one does not exclude its use by others, and it is only partially excludable so that the market alone fails to produce the growth in knowledge stock that optimizes social welfare. Hence, interventions by government or even changes in world prices of traded goods affects the returns to resources required to produce knowledge, and consequently growth in TFP. What is particularly intriguing is the extent of modifications to the RCK type model that is required to make growth endogenous. In addition to an R&D production function, an essential component is the presence of an imperfectly competitive sector. This component, characterized by fixed costs and the production of intermediate input variety, has its roots in the so-called new trade theory.[3]

Fixed costs arise because of the need to purchase the property right to produce a new design before production can take place. In the context of genetically modified organisms, these fixed cost can be envisioned to include laboratory and other expenditures to produce a non-mutant plant with sought-for characteristics. These costs can be large relative to the variable cost of just reproducing from seed the new non-mutant plant. This is a classic market failure problem in which marginal cost pricing will not necessarily lead to cost recovery so that some form of imperfect competition is required in order to recover total costs. The presence of a fixed cost implies that the scale of the market leads to higher profits to the inventor, higher returns to R&D investments, and also to the potential for lower prices to purchasers of the new seeds. In principle therefore, expanding the scale of the market, such as opening a country to foreign markets, can lead to an increase in the rate of growth. Finally, trade can also alter the global availability of knowledge directly or indirectly by trade in knowledge - embodied intermediate goods (via reverse engineering or imitation in the South).

To illustrate these points and to build a base for later discussion, the following section provides a non-technical sketch of a trade – endogenous growth model.[4]

3. An Overview of the R&D-Growth Model

The environment captured by the endogenous growth model is depicted in Figure 1. Consider an open economy that faces perfectly elastic demand for final goods in world markets. The economy contains four sectors, a final goods sector (the only sector which trades internationally), a household sector, a sector that produces intermediate capital variety and an R&D sector. These components are denoted in Figure 1, where numbers in (.) denote key linkages between sectors that are referred to later. The separation of the R&D sector from the capital variety sector is for ease of presentation. The two sectors can be modeled as one without loss of generality. The Figure can be interpreted without the equations, but their inclusion provides deeper insights into the model.

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The two primary factors of production, L and B, are mobile among sectors but immobile internationally. Their levels are constant over time. Producers undertake three distinct activities. Producers in the R&D sector choose the services of two primary inputs, L_m, and B_m, given the stock of existing knowledge M to produce new designs $\dot{M}$. The accumulation of new designs is proportional to accumulated knowledge M which, like a public library, is available to all. New designs should be broadly interpreted to include the production of technical knowledge that is embodied in patents, blue prints, and the discovery of a genetic code. Excluded from this list are trade secrets and process innovations for which some type of property right is not possible. The R&D production function exhibits constant returns to scale over the contemporary inputs L_m, and B_m, chosen by the firm engaged in R&D production. But, the firm takes the stock of knowledge M as given, even though in the aggregate, M depends on the levels of past additions to knowledge and therefore the services of resources that produced these additions. Thus, the production function exhibits increasing returns over all inputs.

Since the cumulative output of each individual firm's R&D activities expands the common pool of technological knowledge M, (e.g., the size of the library) R&D output is a technological spillover, a positive externality which increases the productivity of the two primary factors employed in R&D production. Spillovers are a source of growth in TFP which prevents, over time, the onset of diminishing returns to primary factors and, of course, increasing the efficiency of producing additional new designs. Using GMO as an analogy, growth in M causes the GMO production function in arguments L_m and B_m to shift upward.

The market linking R&D sector output to producers of intermediate capital variety, linkage (4), is competitive. However, there are two unique features. First, each design is associated with only one firm in the differentiated capital goods sector. That is, only a single firm purchases the right to the design so that one design is associated with one type of differentiated capital variety. Second, the design is purchased *before* the production of a particular capital variety can take place, i.e., it is a fixed cost. The uniqueness of each design allows each corresponding capital variety to be differentiated from others. This means that producers of capital variety are monopolistically competitive in the their output market, linkage (6). This allows each firm in this sector to charge a price above marginal cost and thus the opportunity to recover total costs, i.e., to cover the variable costs associated with inputs $Y_{k(s)}$ and $Z_{k(s)}$, and the fixed cost associated with the purchase of the design. The analogy to GMO is that the up-front expenditures must be incurred before reproduction of the new variety can take place. Since each GMO is unique, a firm holding the utility patent has monopolistic power to the extent that a particular variety can substitute for other varieties.

Next, each firm must borrow to obtain the resources to cover the up-front cost of obtaining the patent right to manufacture the new variety. Thus, to purchase a new design, firms must offer households (i.e., lenders) the prospect of relatively high returns to induce them to forego consumption and provide "venture capital" that results in the creation of a new firm. Once obtained, a property right to the knowledge embodied therein is presumed to lie with the producer of the corresponding capital variety forever.

Having incurred the initial fixed costs and thus holding rights to a new design, new firms are presumed to use a constant returns to scale (CRS) technology and employ final goods, $Y_{k(s)}$ and $Z_{k(s)}$, as factors of production to produce intermediate capital, $k(s)$, or in the case of a GMO, to begin the replication of new seeds. The subscript $k(s)$ notation denotes the amount of Y and Z employed to produce capital variety of type s. Capital accumulation is the increase in the number of differentiated capital. Since there is one new firm per capital variety, one capital variety per new design, and since the number of designs are proportional to accumulated knowledge, the number of new firms increase over time, and at any point in time *t*, are proportional to M_t. When the number of designs increases, the number of capital varieties (indexed by *s*) also increases and, hence, capital accumulation occurs.

Firms in the differentiated capital sector are presumed to have forward looking behavior; they make an investment decision to buy a new blueprint and produce capital variety so as to maximize the long-run expected returns from an infinite stream of monopoly revenues. A capital market non-arbitrage condition, linkage (3), requires the value of a firm equal its aggregate investment expenditures, which include the cost of a new blueprint plus the cost of final goods employed in the production of a capital variety. The monopoly rents are the incentives necessary for households to forego consumption in order to provide "venture capital."

The final goods sector uses CRS technologies and rents the services of the primary factors *L*, and *B*, and the services of intermediate capital variety *k(s)*. Two features of the technology should be noted. The first and the most important is the employment of capital variety, represented by the term:

(1) $$\left(\int_0^M K_y(s)^\delta \, ds\right)^{1/\delta}, \; 0 < \delta < 1$$

in the production functions depicted in Figure 1. Equation (1) indicates that as *M* gets larger, the number of different factor varieties employed increases. Next, notice that (1) is akin to a CES function in capital variety, $k_y(s)$, where the parameter δ implies that the various varieties of capital are imperfect substitutes. This parameter effectively limits the power of the monopolist suppliers (linkage 6) to announce prices above marginal costs. This margin tends to fall as *M* rises, and reaches a constant value in long-run equilibrium, i.e., the steady state. Final good suppliers face competitive output markets, linkages (1, 2, 7). Finally, note that the final goods sector and the R&D sector compete for the services of the same primary resources that are limited by the total stock *L* and *B* available.

Households own the primary factors and the equity of monopoly firms. They make consumption decisions, incur expenditures *E* and save $\dot{a}$ to maximize their inter-temporal utility function subject to an inter-temporal budget constraint. Wealth accumulation occurs as the stock of differentiated capital grows, and as real rental rates W_L,W_B of primary factors rise.[5]

3.1 Major Implications To Growth

Several features of the model affect the economic growth rate. First, economic growth will not occur if, (a) households are unable to save due, for example, to the non-existence of a capital market (linkage 3); (b) markets do not exist for designs or patent rights (linkage 4); or (c) firms producing differentiated capital are not permitted to earn monopoly profits (linkage 6). Whether these linkages exist in an actual economy often depends on its level of development. In the space of human history, these social inventions are relatively recent which has led some authors (Jones,

1998) to suggest that the lack of these institutions helps explain the mere 0.075 percent rate of growth in the world's population from 1 A.D. to 1700, and only 0.0007 per cent per year from 1 million B.C. to 1 A.D. Thus, economic growth is shown as being "institution sensitive."

Second, the two major market imperfections, the non-rival and only partially excludable nature of the stock of knowledge *M*, and the imperfectly competitive structure of the market for capital variety suggest that the market driven rate of economic growth is likely to be less than the rate of growth obtained if government could somehow correct for these failures. Several types of policy interventions can increase the market rate of growth. These include policies that correct the imperfections caused by the non-rivalness and partial excludability of common knowledge; policies that correct for the market distorting effects of monopolistic competition; and policies that intervene in trade to alter the relative prices faced by producers of final goods *Y* and *Z*.

While the effects of these policies are simulated using an empirical model in the next section, it is useful to first discuss their qualitative effects. An ad valorem cost subsidy to producers of R&D, linkage (5), encourages them to bid primary resources away from the final goods sector and to increase the production of new designs. A subsidy to employers of differentiated capital, linkage (6), accomplishes the same result except the economic signal must be transmitted from the final good producer all the way down the market chain to producers of R&D. Thus, a subsidy to employers of differentiated capital increases the derived demand for *k(s)*, which in turn, provides incentives for new firms to enter the production of new capital variety. The entrance of new firms bids up the price of new designs $\dot{M}$, which in turn stimulates their production. Another way to influence growth is through trade policy, linkage (1). Since primary factor rental rates W_L *and* W_B, and the price of designs P_m are functions of the exogenous world prices, trade taxes or subsidies change these values, and hence the profitability and production of R&D activity.

To see the latter linkage, suppose that *Y* is an import-competing good which uses labor L_y intensively, and that the R&D sector also uses labor L_m intensively. An increase in the international price of *Y* causes the labor rental rate W_L to rise relative to the rental rate of the other primary factor *B*. Labor is attracted to the production of *Y* and away from *Z*. While the derived demand for factor variety $K_y(s)$ in sector *Y* rises, the derived demand for capital variety in *Z* falls, leaving the net change in factor demand indeterminate, but likely small. The rise in the rental rate of labor to the R&D sector increases that sectors labor cost so that, in the new equilibrium, the production of new designs $\dot{M}$ falls even though the price of designs P_m may rise. The rate of economic growth, savings $\dot{a}$ and welfare fall. Suppose instead, that an ad valorem negative tariff is imposed to subsidize imports of *Y*. Then, the story unfolds in reverse "order," as growth and welfare rise. Thus, by distorting the relative price faced by final good producers, growth and welfare *can* rise.

3.2 Key Implications To Institutions and Trade

An important implication of the R&D based models for trade and growth is that institutions matter, a strength which we feel others often neglect to mention.[6] Institutional structures and technological developments (such as the emergence of practical biotechnology protocols for creating genetically modified plant varieties) that serve to strengthen incentives to forego consumption, linkage (3), including access to foreign savings, stimulates growth. Another institutional parameter is the provision of property rights to new designs (such as utility patents for GMO), linkage (4), and policies to regulate monopolistic behavior, linkage (6), which is necessary to provide incentives to produce differentiated capital that maximizes the discount income stream of future designs. Another "institutional" factor relates to the R&D technology, and the human and institutional capital implicitly required to make R&D output $\dot{M}$ contribute to the stock of technical knowledge *M*, and then to make this stock of knowledge common. All of these factors, perhaps further stimulated by advances in information technology, appear to be playing a major role in the second wave of world globalization (Baldwin and Martin, 1999). In the case of GMO, countries that are unwilling to recognize the property rights granted by utility patents, are unlikely to see the emergence R&D activity in this regard, neither from domestic nor from foreign GMO firms.

While these are some of the institutional implications of the framework, how institutional changes come about are obviously outside of the framework. As Ruttan (1998, p. 22) notes, "Answers to more fundamental questions, such as why some countries save and invest more than others, why some countries invest a larger share of GNP on education or on R&D, why some countries were able to put the package of high pay-off inputs together more effectively than others, or why some countries have responded to shocks more effectively than other countries remain beyond the reach of models employed by both the neoclassical and the new growth economists."

The R&D version of the new growth theory also makes clear that factor endowments, at least as defined in static neo-classical trade theory, are not necessarily the source of a country's comparative advantage. In fact, the model identifies foreign trade in four factors as having implications to growth. These are trade in (1) final goods (Y, Z), (2) differentiated capital *k (s)*, (3) new designs $\dot{M}$, and (4) international access to the pool of technical knowledge *M*. Effectively, primary endowments are no longer a major source of a country's comparative advantage. Instead, the design and effectiveness of institutions, as mentioned above, policy interventions that correct for market failures in ways that encourage R&D activity (which is shown in the empirical model of the next section), and in the presence of fixed costs, openness to world markets allows for scale effects which further enhances growth.

In this regard, Taylor (1996) lists four separate effects through which "openness" to international markets in goods (Y, Z), knowledge *M*, and factors *k (s)* can affect a nation's trade pattern and growth rate. These effects are (*a*) scale, (*b*) allocation, (*c*) spillovers, and (*d*) redundancy effects. Scale effects come about from integrating the flows of knowledge, goods and factors. Allocation effects are induced by trade which alters relative commodity prices and, through the factor rental rate - world price linkages, affects the profitability of R&D activity. Embodied in the importation of the final goods *(Y, Z)* is capital variety *k (s)*, equation (1). Embodied in the capital variety are the designs and technological knowledge *M*. This information can, in principle, be deciphered with no additional patent cost by the importing country. The result is a positive externality, or technological spillover, from the exporting to the importing country. In either of these cases, policies that encourage openness in trade can have strong effects on growth and specialization. This linkage is considered in more detail in section 4.2.

GH (1991c) show that when countries share a common pool of technical knowledge *M*, (such as might be the case with North America, the European Union, Japan and a few other countries), a national advantage in the research lab can derive only from differences in factor costs. Then, all else constant (including institutions) long-run patterns of specialization and trade depend solely on countries' relative factor endowments, much as in the static theory. If instead accumulated knowledge bears some of the characteristics of a *local* public good, then, initial conditions (e.g. prior experience, stock of technical knowledge, institutions) can influence the allocation of resources to research activities, and ultimately a country's trade pattern and growth rate relative to other countries. In this case, all else the same, a country with greater stock of knowledge capital enjoys an initial advantage in R&D.

Since the market determined rate of growth may be suboptimal (as mentioned above), it is possible for the "lagging country" to catch up by interventions to increase its stock of technical knowledge, as appears to be the case of Japan (Diao et al, 1999). Such interventions could include, as previously mentioned, an ad valorem cost subsidy to producers of R&D patents, linkage (5), and/or an ad valorem rental price subsidy to the employers of differentiated capital, linkage (6). Interestingly, to catch up, these interventions need *not* be permanent, a case of policy *hysteresis*, i.e., a temporary policy having permanent effects.

Since knowledge is a non-rival good, redundancy in knowledge production is a waste of resources. Trade policy can lower this redundancy, and thus save resources. This suggests that countries may seek a niche in R&D activity. On the other hand, trade policies that tend to close an economy tend to induce a country to produce its own knowledge without drawing upon the stock already available elsewhere. Foreign trade in goods provides an economic incentive to eliminate duplication and competitive forces push resources out of redundant R&D activities.

The over-riding implication of this discussion is the point emphasized by Romer (1992, p.86) "..we must recognize that ideas are economic goods which are unlike conventional private goods and that markets are inherently less successful at producing and transmitting ideas than they are with private goods." The two safe policy implications, particularly for developing countries, is that integration with world markets offers large potential gains, and policies to increase savings and schooling are likely to complement the gains from openness.

4. Empirical Application of the R&D Model

We now turn to the discussion of two empirical applications of the R and GH- based model. The first model is calibrated to US level data by Diao and Roe (1997). The second is the summary of a North - South trade and growth model developed by Datta and Mohtadi (2000). The models essentially have the same structure as depicted in Figure 1, except for modifications stipulated by data, such as two-way trade. These studies provide quantitative insights into the effects of policy on growth rates and trade.

4.1 An R&D Model of the US Economy

The US model contains four final good sectors, agriculture and food processing, mineral and materials, manufacturing, and services. Each sector produces a single output using inputs of two non-augmented factors (*L*, *B*) a set of differentiated capital *k (s)* which accumulates, and a set of other intermediate goods. Since bidirectional sectoral trade is observed in the data, exports of each domestically produced good are derived from a constant elasticity of transformation function, while the demand for domestic goods are treated as imperfect substitutes for foreign goods through an Armington system. The model is specified in discrete time and solved using GAMS software. The transitional dynamics are obtained over an interval of 200 years, with intra-temporal equilibria spaced one year apart.

As the discussion in Section 3 indicates, the results obtained will be sensitive to relative factor intensities in production, and the extent to which domestic prices are affected by trade policy. The data for the US suggest that the R&D sector, in terms of the quantity of quality adjusted labor, is relatively labor intensive. Agriculture is relatively capital intensive, while manufacturing, in contrast to agriculture, is labor intensive. Data on US foreign trade reveal a tariff rate of 19 percent for agriculture, and zero for services. The experiments performed entailed the imposition of tariffs, (Figure 1, linkage 1), an input subsidy to producers of new designs (linkage 5), and an input subsidy on the purchase of intermediate capital variety (linkage 6).

Key results are reported in Table 1. They are reported relative to a benchmark, or base-run path. Hence, transition results for year 1 are compared to transition results for year 1 of the base-run, and steady state results are compared to the corresponding year of the steady state results of the base-run.

The first important result is that trade policy affects growth, but the effect on growth is very small. Protecting US agriculture, a relatively capital intensive sector, causes the cost of labor to fall. This fall reduces slightly the cost of R&D activity, resulting in an increase in R&D output, an increase in the production of differentiated capital, and an increase in the rate of GDP growth in the steady state. Notice however, that the rate of GDP growth is only 0.05 percent higher in the steady state than in the base run's steady state. Since this result might obtain because agriculture employs a small share of US labor, an experiment in which the manufacturing sector is protected is also performed.

Protecting the manufacturing sector, which is labor intensive relative to agriculture, causes the rate of steady state growth to fall. However, the decline is once again small, only 0.08 percent. Nevertheless, a significant result is that protecting agriculture causes agricultural output to increase by over 4 percent, and in the long run, the level of real US GDP is higher than GDP of the base run's long-run equilibrium by about 0.11 percent.

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The remaining two experiments entail, respectively, a 10 percent ad valorem subsidy to R&D production (linkage 5, Figure 1) and an ad valorem subsidy to the purchasers of differentiated capital, (linkage 6). A lump-sum household income tax is imposed simultaneously to assure that the budget for these transactions is balanced. In the case of the R&D subsidy, the lump-sum tax is equivalent to 1.3 percent of total household income. The subsidy to buyers of differentiated capital equals 2.7 percent of household income. Since, as noted above, these are the markets that depart from the perfect competition, we expect these interventions to increase overall welfare. The key question is whether these interventions are more effective than the trade interventions just analyzed. The answer is affirmative. The basic results show relatively large welfare increases, and gains in the rate of growth. In the steady state, US GDP grows at a rate that is almost 12 percent higher than that of the base run.

The mechanics of adjustment to the R&D subsidy are as follows. A reduction in R&D costs induces a decline in the market price of new designs as production of new designs rise. This decline provides incentives for households to advance venture capital so that new monopolistically competitive firms can enter the capital production sector. Initially, the output of all sectors except manufacturing fall because households, seeing a new opportunity to invest, forego consumption of final goods, while at the same time the subsidy allows the R&D sector to bid some primary resources away from final goods production. The output of manufacturing rises because the technology for producing differentiated capital uses manufactures intensively. Monopoly profits per firm fall along the entire transition path as a result of a decline in the demand for each variety and the increase in the number of varieties of capital. The increase in the number of capital varieties exceeds the fall in profits per firm however, so that the sum of monopoly profits of all firms in the capital variety sector increase. An increase in the accumulation of differentiated capital along the transition path is required to “compensate” the final goods sectors' “loss” of the primary resources that are initially reallocated to R&D production.

From the perspective of households, changes in their consumption and savings reflects the outcome of intertemporal decisions over the entire path. Household savings rise throughout the time path, while household consumption falls in the first year and then rises along the transition path. Consumption does not exceed consumption levels of the base run until period 21. In the long run, the pool of common knowledge *M* grows. Concomitant with the increase in the production of new designs and capital variety, is the employment of a larger share of the economy's primary resources in the production of R&D, and the production of a larger number differentiated capital substitutes for primary resources in final production. Since trade in this model must be balanced, both exports and imports grow.

While the results of an ad valorem subsidy to purchasers of capital variety, linkage (6), are similar to the R&D subsidy, the mechanics of adjustment are quite different. The initial direct beneficiaries of the subsidy in this case are producers of final goods. The subsidy induces them to increase capital demand. The monopoly price for capital is a mark-up price chosen by the monopoly firms based on the marginal cost of capital production, and the interest rate. The increase in capital demand causes the interest rate to rise, which in turn induces producers of differentiated capital to respond by raising the price of capital they lease to final good producers. Given the subsidy to final good producers, the market for differentiated capital clears at a higher price to producers of differentiated capital and a lower price to employers of differentiated capital (because of the subsidy – price wedge). The rise in monopoly profits to holders of new designs induces an increase in forgone consumption and investment in new designs rise. The increased investment demand bids up the price of new designs and the allocation of more resources to R&D production. As in the case of the R&D subsidy, the initial increase in foregone consumption and the increase in primary resource demand by the R&D sector causes the output of agriculture, minerals and materials and the service sector to decline. Manufacturing output tends to rise since the production of differentiated capital uses manufacturing output intensively. As new designs are produced and differentiated capital rises, the output of all sectors rise. In the steady-state, the growth of the economy is increased by almost 12 percent over the bench mark steady state growth rate.

While the framework helps organize and provide consistency to our thinking about the sources and conditions for economic growth, much of which would seem applicable to agriculture, the model is highly aggregated. It would be useful to disaggregate human capital into categories with special attention to scientific capital, to specify separate sectoral R&D production functions with the possibility for technological spillovers from one R&D sector to another as other work finds (Gopinath and Roe, 2000), and to account for the effect advances in information technology have upon the efficiency of the R&D production function. Thus, as mentioned in the introduction, much remains to be done.

4.2 Technological Spillovers and North – South Trade

The treatment of the role of international trade in the new growth theory centers on the ways in which trade enables the diffusion of technology. Spillovers from North to South occur when the South deciphers the Northern know-how by *"reverse engineering"* the imports from the North (e.g., GH 1991a, b; Helpman 1993). Datta and Mohtadi (2000) (DM) provide a model that shows explicitly how this occurs. The relevance of the DM paper to agricultural trade relates to the diffusion of knowledge via trade in transgenic products.

One of the main results of DM's paper is that innovation and imitation can lead to gains from trade in *both* the North and the South. While innovation drives growth in the North, as in the model above, trade helps to facilitate the innovation process further. This happens because, (a) North imports consumption goods from the South, releasing human capital from final goods production to the research sector, thus leading to higher innovation, and (b) the North exports intermediate goods to the South, expanding its human capital intensive R&D sector. On the other hand imitation cuts down on the time and cost of product development in the South thereby leading to higher growth. Thus, trade contributes to the productivity of the North in the following ways: (a) new 'technologically superior' imported intermediate goods complement and enhance the productivity of domestic resources, (b) foreign technology is imitated and adapted for domestic use, and (c) trade raises productivity of both the North's `innovation' sector and the South's 'imitation' sector.

The key component of the DM paper is the process of "reverse engineering." Through this process the South imitates North's technology, using an R&D type mechanism similar to Figure 1, but with the major exception being that the South's learning leads to the accumulation of a new kind of knowledge, i.e. *"imitation knowledge"*. This accumulation raises the productivity of the South, in the same way as true innovations would in the North. The North maintains its comparative advantage in R&D and therefore retains its role as an innovator. The South does not innovate initially, given its low productivity in innovation activity, but with sufficient enlargement of its human capital base, it approaches an innovator state eventually.[7]

In agriculture this raises intriguing new issues with respect to biotechnology; that is, whether the same reverse engineering process that has characterized trade with the South in the manufacturing sector will also come to dominate trade in GMO's. Although the nature of GMO driven R&D in agriculture is such that the likelihood of *direct* reverse engineering by an importing country is small because of both its organic structure, and its dependence on local environments, the possibility of reverse engineering in the *method* remains. In this sense, the knowledge of the particular genetic modification may be useful in so far as it would inform the local experts on the possibilities for learning, as opposed to direct imitation. As such, organizations such as the International Service for the Acquisition of Agri-business Applications (ISAAA) have been formed to facilitate such knowledge transfer.

Reverse engineering in GMO products may still be a threat to private owners of patents, however. For example, a study by Traxler, et. al. (1999) shows that the South's ability to protect intellectual property rights is one of the factors that would induce the Northern multinationals to enter the LDCs. The implication is of course that imitation remains a possibility (and thus a threat to the Northern firm) in the biotechnology sector as in the case of industrial technology. In fact, as GH (1991c) point out, imitation by the South is profitable under certain conditions: First, enforcement of patent rights should be not too strict to make imitation prohibitively expensive; second, production costs in the imitating country must be sufficiently low to allow the imitator to capture market share by underpricing the original inventor, and third the South must not re-export its imitated capital variety designs back to the North. This is true of many developing countries with large domestic markets like India and Brazil. What explains this behavior? Imitation generally occurs with a lag. By the time southern producers successfully imitate and start producing the clones, northern consumers have moved to newer upgrades of the product. This is especially true in the market for computers, where a newer generation of computers often makes the older varieties obsolete. Before we explore the additional implications of the model for the case of trade in agricultural biotechnology, we outline some of the highlights of the DM model.

An important finding of the DM model is that trade with the South is unambiguously beneficial to the North, as it is in the former model. Effectively, trade allows for the specialization and division of labor in the North which encourages innovation but it also encourages the South to imitate. Consequently, the North grows more rapidly than under autarchy. For the North, trade with the South releases human capital from the manufacturing sector (i.e., Baldwin and Martin's de-industrialization of the North from labor intensive manufactures), which can be allocated to greater research activity, thereby leading to higher growth. This result is supported by the observation that one of the largest contributing factors to economic growth over the past several years in the US came from increasing exports of the innovation-intensive sectors of the US economy (e.g., the computer industry) to those regions of the world with the greatest imitation potential. But is this result likely to apply to the case for trade in agricultural biotechnology? One crucial difference is the well known fact that the transfer of biotechnology requires *adaptation* to the local agro-climatic conditions, and thus a certain degree of *labor force training* in the South is required as the new imitation is not productive if it does take account of this difference. But if labor force training increases the stock of human capital in the South, the DM model predicts that the effect, while generally benefiting the South, may or may not accelerate the North's growth rate, as this may either reinforce or dampen the South's demand for intermediate capital goods from the North (in this case, transgenic seeds).

The key variable here is that of trade in intermediate capital variety (or “knowledge” goods, e.g., seeds in the biotechnology sector). In particular, DM find that when the South is human capital poor, more training also requires more knowledge goods to be imported from the North (complementary inputs), dampening the contribution of human capital to South's growth, but contributing to the North's growth. However, for Southern countries with larger stock of human capital, labor force and knowledge capital are substitutes, so that further training of the labor force reinforces its contribution to the South's growth by reducing the South's imports of knowledge goods imported from the North

These results also show another interesting characteristic of the new theory. If the South continues its imitation activities, then eventually its stock of knowledge grows to rival that of the North. In this case, it is possible for the South to become equally competitive and even exceed the per capita income of the North. This illustrates, as does the model discussed above, that comparative advantage is no longer determined by a country's primary resource endowments, but instead, its endowments of human capital, i.e. “knowledge capital” and, of course, the quality of its institutions as discussed in the previous section. These attributes of the framework make it appealing to guide our thinking about the second wave of world globalization.

5. Policy Models And Economic Growth, Endogenous or Exogenous?

Is there econometric evidence to support the new growth theory? An excellent review of the econometric based literature on economic growth is provided by Temple (1999). Given the complexity of the new growth theory, no econometric based study has attempted to estimate a structural R&D based model. Instead, the studies have attempted to confirm various sub-components of the theory, or the predictions of the theory. A recent example of the former is a study by Porter and Stern (2000). They find empirical support for an R&D production function of the nature presumed by the new theory. It seems reasonable to conclude that the answer is yes, but the process of technological change and growth is more complex than depicted by the various varieties of the new growth theory. At this stage, the analytical restrictions necessary to fit such a model to data for policy purposes seems too restrictive. Thus, the main conclusion is that the new growth theory is an excellent framework to guide and clarify out thinking about technological change, trade and growth. But the direct application of this framework in terms of an empirical policy model of the calibration type appears premature.

This view is not to imply of course that we should lesson our efforts to model growth in policy models. Of the three major contributors to economic growth, labor, capital and TFP, growth accounting studies typically find that growth in labor and capital account for more than 70 percent of growth in GDP, with growth in factor productivity typically accounting for less than 30 percent, and often only 10 to 15 percent in advanced economies. It is typically difficult to model fertility decisions, which change slowly over time in any case, which leaves roughly 30 to 40 percent of growth that can be feasibly and meaningfully model as the result of agent decisions. Using growth accounting results or other estimates of growth in TFP, the exogenous growth models of the Ramsey genre offer opportunities to provide policy insights into roughly this 30 to 40 percent of the economic forces affecting growth. Attempting to depict dynamic phenomena with behaviorally inconsistent recursive and otherwise static models is, in my view, not acceptable to the broader economics profession, and should not be acceptable to applied economists in general.

Moreover, coming to grips with the major economic forces causing transition dynamics (short-run phenomena) and persistence (long-run phenomena), forces discipline on judging the degree to which a model replicates an economic process as well as lessoning the likelihood of drawing erroneous conclusions from model experiments. Discipline tends to be forced because it seems more natural to contrast the time path of an actual economy with the time path given by the model than it is to ask the same questions of an essentially static model. The fact that a rather simple though aggregate model of the Ramsey genre can reasonably characterize the path of a real economy is illustrated in a paper given at this conference. The lower likelihood of drawing erroneous conclusions from model experiments occurs because model results can be contrasted to historical data, and further, the results from modeling agent's choices over time typically depart from the results obtained from static models. This result is evident in Diao, Agapi and Roe (2001) where they find from a global dynamic model of the Ramsey genre that the longer run result of world-wide agricultural reform under the WTO results in far fewer *losing* countries than depicted by a static version of the otherwise same model.

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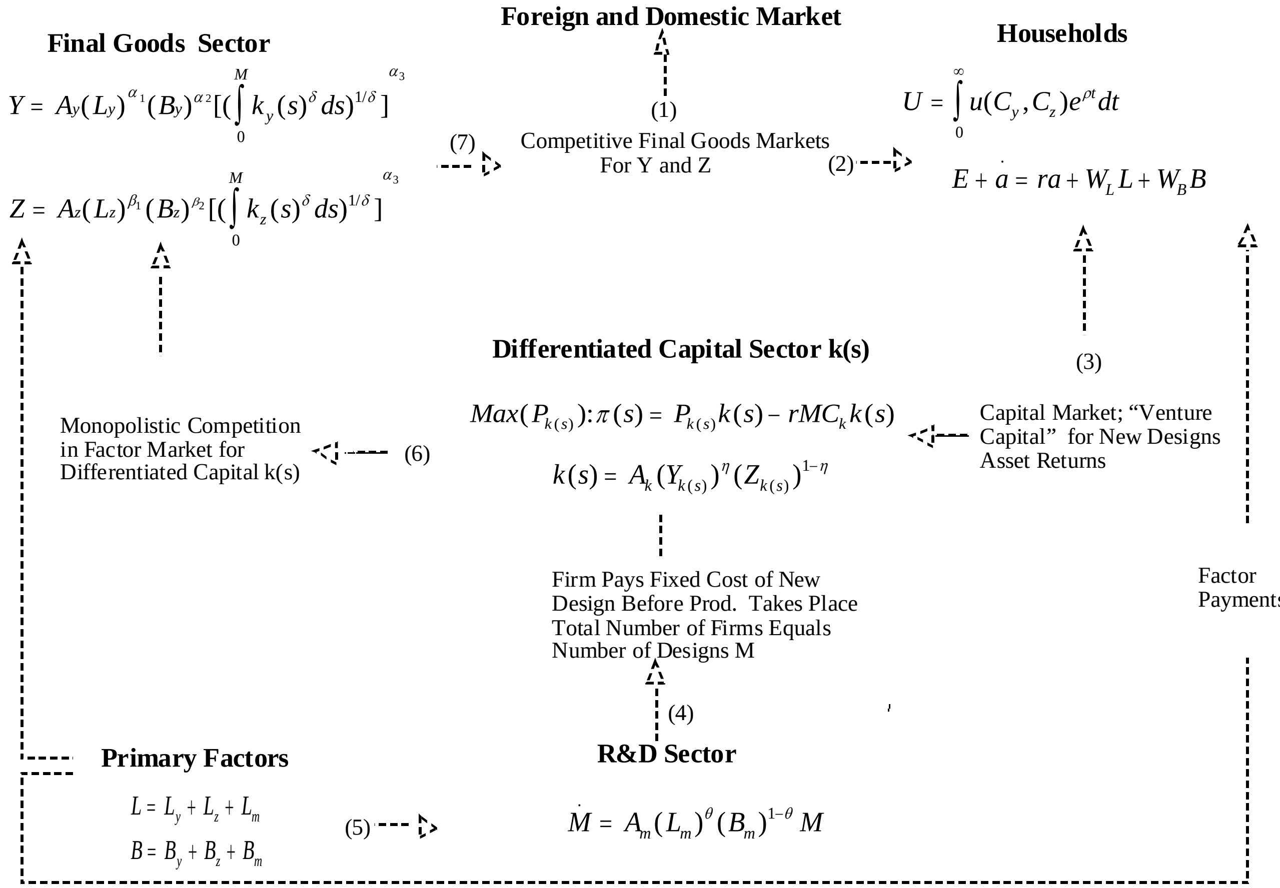
Table 1: Selected Results From An R&D Based Growth Model of the US.

	Percent Change Relative to the Base Run					
	GDP Level	Agr. Output	Mat. Output	Mnfc. Output	Serv. Output	GDP Grth
30% Ag. Tariff						
Year 1	-0.1103	4.2063	-0.4812	-1.5872	-0.0232	
St. State	0.1071	4.4080	-0.2761	-1.3655	0.1803	0.05
30% Mnfc. Tariff						
Year 1	-0.7582	-2.8648	-3.1700	1.114	0.0149	
St. State	-3.0506	-5.7302	-4.8606	3.3403	-2.4179	-0.08
10% R&D Sub.						
Year 1	0.1134	-1.8474	-1.3545	0.7241	-1.785	
St. State	68.100	65.2400	65.2200	65.8800	65.0111	11.82
10% *k (s)* Sub.						
Year 1	0.1503	-2.1175	-1.3074	1.7510	-1.9390	
St. State	75.3300	71.5200	72.5900	76.9600	71.6900	11.79

Source: Diao and Roe, 1997


Final Goods Sector
$Y = A_y(L_y)^{\alpha_1}(B_y)^{\alpha_2}[(\int_0^M k_y(s)^{\delta} ds)^{1/\delta}]^{\alpha_3}$
$Z = A_z(L_z)^{\beta_1}(B_z)^{\beta_2}[(\int_0^M k_z(s)^{\delta} ds)^{1/\delta}]^{\alpha_3}$
Foreign and Domestic Market
(1)
(7)
Competitive Final Goods Markets For Y and Z
(2)
Households
$U = \int_0^{\infty} u(C_y, C_z)e^{\rho t} dt$
$E + \dot{a} = ra + W_L L + W_B B$
Differentiated Capital Sector k(s)
(3)
$Max(P_{k(s)}): \pi(s) = P_{k(s)}k(s) - rMC_k k(s)$
$k(s) = A_k(Y_{k(s)})^{\eta}(Z_{k(s)})^{1-\eta}$
Monopolistic Competition in Factor Market for Differentiated Capital k(s)
(6)
Capital Market; "Venture Capital" for New Designs Asset Returns
Firm Pays Fixed Cost of New Design Before Prod. Takes Place Total Number of Firms Equals Number of Designs M
Factor Payments
(4)
Primary Factors
R&D Sector
$L = L_y + L_z + L_m$
$B = B_y + B_z + B_m$
(5)
$\dot{M} = A_m(L_m)^{\theta}(B_m)^{1-\theta} M$

[1] For example, Stiglitz (1996), in his review of the growth experience of East Asian economies suggests that the determinants of growth are generally caused by a host of market failures that vary by country and by the level of development.

[2] Barro and Sala-i-Martin (1995) provide an excellent treatment of this approach in Chapters 2 and 3.

[3] A review of this literature is provided by Krugman (1995).

[4] R&D models specified to easily illustrate their basic properties can be found in Jones (1998) and Aghion and Howitt (1998).

[5] It is tempting at this point to contrast this model with the partial equilibrium framework of induced innovation developed by Ahmed (1966) and applied and extended by Hayami and Ruttan (1971). In the Ahmed model, the unit isoquant referred to as the Innovation Possibilities Frontier (IPC) is the culmination of the stock of knowledge at a point in time from which an invention (or technique) is produced. Bias in the direction of technological change occurs so as to save the relatively most scarce factor of production. The R&D model can, loosely speaking, be seen as endogenizing the IPC, except that the direction of technological change in the R&D model is Harrod neutral.

[6] This appears to be one of the main points of departure seen by Ruttan (1998) between the new growth theory and development economics.

[7] Connolly (1998) models the case where the South also innovates. He likens this case to Advanced Micro Devices, Inc. and Samsung which first reversed engineered and cloned Intel's 386 and 486 chips in the 80's and early 90's, but have since begun producing their own microprocessor chips, first the K5 and now the K6.