

OLIGOPOLISTIC COST INNOVATION, STOCK MARKETS, AND MACROECONOMIC DEVELOPMENT

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Abstract

This study investigates the strategic supply and investment behavior of oligopolistic firms in a dynamic general equilibrium framework. By investing in innovations, firms can reduce future production costs. A knowledge spillover enhances the effectiveness of firm investments. Depending on Cournot-type strategic incentives in the oligopolistic market and on general-equilibrium responses of other markets to firms' choices, firms may choose higher investment ratios, and boost dividend- and industry growth. Households, observing stock-value trends, adjust their investment in firm stocks. In such an economic environment, oligopolistic incentives and choices play a leading role, and the oligopolistic concentration of market power influences critically both industry- and economy-wide growth. Depending on consumer preferences, the model yields an inverse-U relationship between product-market competition, with innovation and growth. Moreover, the model predicts massive short-run rational reactions of stock prices to permanent unexpected entry or exit of firms.

Keywords: oligopoly, cost innovation, spillovers, dynamic games, Tobin's q , growth

JEL classification: D43, E19, E22, G31, L16, O31

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1. Introduction

The “information age” has brought several new “high-tech” consumer products into everyday economic life. Computers, cell phones, software, internet-based products, are a few obvious examples. Since the invention of these products, their suppliers have been, typically, just a handful of oligopolistic firms. Such oligopolistic markets are characterized by strong dynamic competitive incentives. Apart from a typical contemporaneous oligopolistic supply war, there is an additional, equally important aspect of oligopolistic competition: the dynamic war among firms for increasing their productivity. The central goal of this study is to examine the interplay between dynamic oligopolistic competition with explicit productivity-enhancing investment potential by the side of firms and macroeconomic conditions and mechanisms that bring oligopolistic and perfectly competitive markets into a vital dynamic interaction. The focus is on the role stock markets play in capturing and reflecting the growth potential of oligopolistic profits.

Due to the strong incentives arising in oligopolistic competition, firms undertake *conscious* and *costly* economic investments in new ideas in their effort to reduce production costs, despite the fact that these ideas can be perfect public goods, both non-rivalrous and non-excludable. For example, many firms spend significant amounts in basic R&D in their own laboratories or in universities, without claiming patents for new innovations: the results go public in scientific journals, and positive spillover effects to competitors are perfect. Still, firms find it worthwhile to partly internalize the externality, to contribute to R&D, and to progress together with their competitors. Part of their motives is also to gain a higher share of the consumer basket.

The view of this study is that the strategic knowledge investment choices of oligopolistic firms should be studied and understood in general equilibrium. First, the GDP share of

production by firms with market power is significant. Second, oligopolistic industry growth is significantly correlated with economy-wide growth. Third, oligopolistic firms are the biggest share of the total value of stock markets. These three points motivate the following three immediate questions that this paper studies: (i) can oligopolistic investment in innovations be one of the engines of economy-wide growth? (ii) what is the link between the degree of oligopolistic market power concentration and industry growth? (iii) can oligopolistic investments be the engine of dividend growth and stock-market trends?

A model is built where oligopolistic-firm investment choices are at the heart of economic activity. The time horizon is infinite, with a large number of identical infinitely-lived households. There are two types of goods consumed by the households, and two sectors of the economy that produce them. Households are endowed with an initial level of human capital and by devoting time, they can add to their human capital-stock. Their time endowment is allocated among human-capital investments, and work in each of the two production sectors of the economy.

The production sector for the one of the two goods, the numeraire at time 0, is perfectly competitive, using only labor. This labor input is augmented by the stock of human capital that households have accumulated. The second sector, producing a high-tech good, is oligopolistic. A finite number of firms have rights to use a technology that needs a certain type of knowledge.

Firms are the only microeconomic units who know how to invest in extra knowledge that improves the productivity of such machines. In order for firms to acquire new knowledge, they must sacrifice part of their sales profits and channel it to R&D. But although acquiring new knowledge is costly, the new ideas are a perfect public good.

Unlike inventions, innovations are a continuous effort to increase productivity, to lead

to *incremental* technological progress. That is, technological innovations that increase the productivity of labor, without requiring from workers to acquire new types of skill through costly human-capital investment.¹ More strongly, with *incremental* technological progress, workers need not even accumulate more of the same type of skill that they already possess, in order for their labor productivity to increase. Thus, households provide raw labor to the oligopolistic firms and their human capital plays no role, as the production technology developed by firms augments their raw time spent in production, independently of how skilled workers can be. The dual flipside of investing in incremental technological progress is that firms can produce the same amount of final goods at a lower cost. Thus, investment in incremental technological progress is essentially *oligopolistic cost innovation*.

Choosing a higher plowback ratio (re-investment in the stock of knowledge through R&D), firms might be less competent compared to others in the final good market today, but they can be more competent tomorrow, since, by reducing future production cost, their future profit margin will increase. The element of Cournot-type competition is therefore double: in each period there are quantity wars among firms and also investment wars. Firms can balance their quantity attacks in the oligopolistic market today and tomorrow, through pulling the R&D lever strategically today.

Since firms can store and pile up ideas, the stock of knowledge is a state variable. Thus, the Cournot game of the firms is dynamic. But all dynamic-game firm choices are made in general equilibrium, thus, firms take into account how *all* markets respond to their choices.

All firms are owned by households that hold their shares. However, the only investment choice of a household is how many shares of each firm to buy, just by observing dividend growth. The value of the shares held by households is one-to-one tradable with a consump-

¹ The term and definition of incremental technological progress is borrowed from Caselli (1999, p. 79). On the contrary, revolutionary production inventions often require from workers to acquire totally new types of skill.

tion good produced under perfect competition, the numeraire in period 0. However, the knowledge stock alone, is useless to the households. Households cannot exploit this knowledge stock. Instead, the best households can do is to hold shares of firms that make good use of this knowledge: firms produce and sell profitably in the market of the high-tech good. This element contrasts sharply standard perfect-competition Ramsey-type models where, (α') capital is tradable one-to-one with consumption, (β') capital can be used either in order to be rented or in order to be consumed, and, (γ') firms are passive lessees of capital and labor services, with all investment choices left to be made by the “landlords,” the households.

On the basis of the described analytical framework, this study provides three interrelated, testable answers to the three questions, (i)-(iii), above.

(a) With respect to question (i), *oligopolistic investment in cost innovations must be a significant engine of growth* through the following mechanism. While the intra-temporal Cournot competition among firms reduces prices and pushes down revenues and profit margins of oligopolistic firms, more intensive cost innovation *in general equilibrium* is a way to avoid profit-margin losses: if innovation leads the dividends of firms to grow at a higher rate, consumer demand for oligopolistic products can also grow faster and, in the end, the whole oligopolistic industry can capture a bigger share of consumer income spent on the oligopolistic goods. The effort to compete, not only with other firms, but also with *other consumption goods*, leading to more innovation and growth, and the success in capturing a bigger part of consumer income, can stimulate the whole macroeconomy to follow a faster-growth path by increasing and speeding up the real value of stocks held by households.

(b) Although oligopolistic firm strategic incentives and choices depend on the responses of all other markets, *the concentration of market power is a dominant factor in determining industry- and (as suggested in point (a) above) economy-wide growth*. In particular, the

link between the degree of competitiveness and growth can be either positive or negative, depending critically on the elasticity of demand for the oligopolistic good. With a low elasticity of demand, more competition reduces growth. With a high elasticity of demand, the inverted-U relationship between product-market competition and growth documented to hold in empirical work by Geroski (1995), Nickell (1996), Blundell et. al. (1995) and (1999), and Aghion et. al. (2002) is implied by the model. With low competition and a high consumer demand, firms invest more in innovation, despite the fact that knowledge spillovers also make their competitors stronger: higher innovation investment boosts consumer demand and firms can make higher profits. Above a level of competition, firms choose to free-ride on the investment of others: a typical commons problem dominates, and investment and growth fall. The elasticity of demand for oligopolistic goods, the key parameter for linking the model with the empirical facts, is driven by consumer preferences. In particular, with iso-elastic utility functions, a high elasticity of intertemporal substitution of goods is behind a higher elasticity of demand for the oligopolistic goods.

(c) There is a *tight link between industry growth and long-run stock market trends*. With respect to the short run, an unanticipated permanent entry or exit of firms can lead to massive temporary-adjustment changes in the returns of stocks. The economy adjusts from a previous market structure to a new one with consumers spending a different share of their income on oligopolistic goods and the value of the stock market *rationally* adjusts fast to reflect such changes. Critical in determining the magnitude of a temporary stock-market rise or fall, are the forces determining Tobin's q in environments with alternative market structures: Tobin's q , the ratio between the cost for acquiring new knowledge and the ability of this investment to generate future profits is strongly affected by the spillover of knowledge.

Although the existence and nature of equilibrium of the model is tackled analytically,

its solution and characterization of mechanics requires some numerical analysis. A similar version of the structure of the oligopolistic firm problem, is studied in partial equilibrium by Koulovatianos and Mirman (2004).

The paper is organized as follows. In section 2, a simple model with unitary elasticity of demand for the high-tech good is presented, solved and characterized. The tractability of the simple model allows the complete presentation of the model's analytics, easy to follow, and necessary for understanding the more general framework that gives an answer to question (i) above. In section 3, a more general framework is discussed (with formal proofs moved to an appendix), providing answers to questions (ii) and (iii) above. In section 4, a comparison of the model with previous theories is presented, and section 5 is devoted to a few concluding remarks.

2. A tractable model of oligopolistic competition

This section is devoted to a model that ignores empirical facts of the link between market structure and industry growth. The goal of the model is to be tractable, in order to present the derivation of the competitive equilibrium and to enable the exposition of the new concepts.

2.1 Description of the model

Time is discrete and the horizon is infinite, $t = 0, 1, \dots$. The economy consists of three types of microeconomic units.

2.1.1 Oligopolistic firms

There are $N \geq 2$ oligopolistic firms, producing a differentiated, 'high-tech' good, Q . Each firm $j \in \{1, \dots, N\}$, uses a common stock of knowledge at time 0, $z_0 > 0$, in order to produce

the good. For all $j \in \{1, \dots, N\}$, the production technology for producing q_j units of good q is,

$$q_{j,t} = z_t l_{j,t} , \quad (1)$$

with $q_{j,t}$ being the supplied quantity and with $l_{j,t}$ being the labor hours employed by firm j in period t . The cost of each unit of employed labor at time t is $w_{Q,t}$, which is determined in the labor market, where each firm is an oligopsonist of labor.

Knowledge depreciates at the rate $\delta_z \in [0, 1]$. However, each firm $j \in \{1, \dots, N\}$ has the chance to invest in new knowledge and to augment the overall capital stock, through undertaking R&D investment, according to the law of motion,

$$z_{t+1} = (1 - \delta_z) z_t + \theta \sum_{i=1}^N x_{i,t} , \quad (2)$$

where $x_{j,t}$ units of good y is the amount spent in R&D investment by firm j in period t , and $\theta > 0$, captures the effectiveness of R&D spending. Parameter θ is common across all oligopolistic firms. One reason why R&D productivity can be the same across firms, might be that exogenous basic-research findings, non-rival and non-excludable, benefit the research laboratories of each firm in the exact same way. At any time t , the accumulated stock of knowledge of any firm $j \in \{1, \dots, N\}$, is *not* patent-protected, hence *non-excludable*.

The oligopolistic market can be characterized by a set of fundamentals, namely, the N firms, their production functions, given by (1), their initial knowledge-stock endowments $z_0 > 0$, the law of motion for this stock endowment, given by (2), a sequence of inverse-demand functions, $\{P_{Q,t}(Q_t)\}_{t=0}^{\infty}$, that is treated, for the moment, as exogenously given and, also at this point, a stream of exogenously given interest rates, and wages, $\{(r_t, w_{Q,t})\}_{t=0}^{\infty}$.

As a first description, after solving (1) for l_j and substituting it into the firm's cost

function, the problem faced by each firm $j \in \{1, \dots, N\}$, has the form,

$$\max_{\{(q_{j,t}, x_{j,t}, z_{t+1})\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \prod_{s=0}^t \frac{1}{1+r_s} \left[P_{Q,t} \left(\sum_{i=1}^N q_{i,t} \right) q_{j,t} - w_{Q,t} \frac{q_{j,t}}{z_{Q,t}} - x_{j,t} \right] \quad (\text{P1})$$

subject to,

$$z_{t+1} = (1 - \delta_z) z_t + \theta \sum_{i=1}^N x_{i,t} ,$$

given $z_0 > 0$, $\{P_{Q,t}(\cdot)\}_{t=0}^{\infty}$, $\{(r_t, w_{Q,t})\}_{t=0}^{\infty}$, and $\left\{ \{(q_{i,t}, x_{i,t})\}_{\substack{i=1 \\ i \neq j}}^N \right\}_{t=0}^{\infty}$. Each firm $j \in \{1, \dots, N\}$ has a number of common shares, S_j , and it is assumed that this number is constant over time, i.e. firms issue no new equity.

2.1.2 Perfectly competitive firms

There is a large number of firms, with total size normalized to one, producing a consumable good, y , according to the technology,

$$y_t = A h_t l_{y,t} , \quad (3)$$

with $A > 0$, $l_{y,t}$, being the labor hours employed for the production of good y , and h_t being the human capital of workers in this sector.

2.1.3 Households

There is a large number of identical infinitely-lived households with total mass normalized to one. Each household is endowed with a value of $S_0 > 0$ units of shares of the N oligopolistic firms in period 0. The relative price of these shares, in terms of the price of the consumable good y , is also given in period 0, and it is $P_{S,0} > 0$.² By convention, y in period 0 is the numeraire.

² One way of thinking about the initial conditions $S_0, P_{S,0} > 0$ is that they are the features of the initial public offering (IPO) of equity by the firms. But this interpretation is not necessary for the present analysis.

Each household is also endowed with a given initial stock of human capital, h_0 , and with one unit of time in each period. Each period, t , the time of the household is allocated to: (i) work in the competitive sector, providing $l_{y,t}$ units of time, (ii) work in the oligopolistic sector, providing $l_{Q,t}$ time units, and, (iii) time spent for training, denoted as e_t . Future human capital has two inputs, the previous period's human capital and time allocated to training, namely,

$$h_{t+1} = (1 + Be_t - \delta_h) h_t , \quad (4)$$

with $B > 0$ and $\delta_h \in [0, 1]$, being the depreciation rate of human capital.

The utility function of the representative household is given by,

$$\sum_{t=0}^{\infty} \beta^t [\chi \ln(c_t) + \psi \ln(Q_t) + (1 - \chi - \psi) \ln(1 - l_{y,t} - l_{Q,t} - e_t)] , \quad (5)$$

where $\beta, \chi, \psi \in (0, 1)$, and c_t are the consumed units of good y , whereas Q_t are the consumed units of good Q , in period t . In each period, the households receive a labor income from the N oligopolistic firms, $w_{Q,t}l_{Q,t}$, and also from the perfectly competitive firms, $w_{y,t}l_{y,t}$, with $w_{Q,t}$ and $w_{y,t}$ being the wage rates in each sector. The households also have the potential to make an income from receiving dividends, d_t per share, and also from a potential appreciation of their stocks. Once firms, in the beginning of each period, operate, i.e. produce and supply goods, of a total quantity $Q \equiv \sum_{i=1}^N q_{i,t}$, pay wages, $w_{Q,t}$ to their total hired labor, $l_{Q,t} \equiv \sum_{i=1}^N l_{i,t}$, perform knowledge investments of a total value $x_t \equiv \sum_{i=1}^N x_{i,t}$, they distribute dividends d_t per share, their stocks are traded in the stock market and a new stock price is formed, $P_{S,t+1}$. Thus, the budget constraint of the representative household is given by,

$$S_{t+1}P_{S,t+1} = S_t(P_{S,t+1} + d_t) + w_{y,t}l_{y,t} + w_{Q,t}l_{Q,t} - c_t - p_{Q,t}Q_t , \quad (6)$$

where $p_{Q,t}$ is the market price of good Q in period t . Letting,

$$a_t \equiv S_t P_{S,t} \quad (7)$$

denote the total value of assets held by each household in the (“very”) beginning of each period, (with $S_0, P_{S,0} > 0$ as given, $a_0 > 0$ is also a given initial condition for each household), the household budget constraint, (6), can be written equivalently as,

$$a_{t+1} = (1 + r_t) a_t + w_{y,t} l_{y,t} + w_{Q,t} l_{Q,t} - c_t - p_{Q,t} Q_t, \quad (8)$$

where,

$$1 + r_t = \frac{P_{S,t+1} + d_t}{P_{S_t}}, \quad (9)$$

i.e. the gross effective interest rate equals the sum of the gross capital gains from the appreciation of each share and the dividend per (initial) share value. This interest rate is the discount factor of firm profits in problem (P1) of each firm and equation (9) is discussed and cross-checked later on, while presenting the way of pricing the shares oligopolistic firms in equilibrium.

2.2 Partial-equilibrium necessary optimality conditions

Although for describing the model it was convenient to start from the oligopolistic firms, it is now convenient to reverse the order and start describing the problem of the household. One important reason for this change in exposition is that the household behavior determines the parametric form of the sequence of demand functions $\{P_{Q,t}(\cdot)\}_{t=0}^{\infty}$ faced by oligopolistic firms.

2.2.1 Household partial-equilibrium necessary conditions

Using the notation introduced by (7) and (8), the problem of the representative household is,

$$\max_{\{(c_t, Q_t, l_{y,t}, l_{Q,t}, e_t, a_{t+1}, h_{t+1})\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t [\chi \ln(c_t) + \psi \ln(Q_t) + (1 - \chi - \psi) \ln(1 - l_{y,t} - l_{Q,t} - e_t)] \quad (P2)$$

subject to,

$$a_{t+1} = (1 + r_t) a_t + w_{y,t} l_{y,t} + w_{Q,t} l_{Q,t} - c_t - p_{Q,t} Q_t ,$$

and,

$$h_{t+1} = (1 + B e_t - \delta_h) h_t ,$$

given $a_0 > 0$, and $\{(p_{Q,t}, r_t, w_{y,t}, w_{Q,t})\}_{t=0}^{\infty}$.

The necessary optimality conditions are,

$$p_{Q,t} = \frac{\psi}{\chi} \frac{c_t}{Q_t} , \quad (10)$$

$$\frac{c_{t+1}}{c_t} = \beta (1 + r_{t+1}) , \quad (11)$$

$$\frac{1 - \chi - \psi}{\chi} \frac{c_t}{1 - l_{y,t} - l_{Q,t} - e_t} = w_{y,t} , \quad (12)$$

$$r_{t+1} = B (l_{y,t+1} + e_{t+1}) - \delta_h , \quad (13)$$

$$w_{y,t} = w_{Q,t} , \quad (14)$$

together with (8), (4) and a standard transversality condition. It is notable that condition (10) has revealed the parametric nature of the inverse-demand function for good Q in each period. These conditions, which are also sufficient for an optimum, lead to decision rules as functions of assets, a_t and human capital, h_t , in each period for any given prices $\{(p_{Q,t}, r_t, w_{y,t}, w_{Q,t})\}_{t=0}^{\infty}$ also expressed as functions of (a_t, h_t) . But before rushing into expressing the demand function for good Q as a function of (a_t, h_t) , only, it is important to include the state variable z_t as well, because this will be true in general equilibrium. Attention is paid to finding a set of Markov-perfect Cournot-Nash equilibrium strategies, of firms, namely a set of supply and investment rules,

$$\left\{ Q^i (a_t, h_t, z_t), X^i (a_t, h_t, z_t) \right\}_{i=1}^N ,$$

so, in general equilibrium the price vector $(p_{Q,t}, r_t, w_{y,t}, w_{Q,t})$ will also be a function of (a_t, h_t, z_t) . Thus, attention is restricted to any sequence of prices as functions of (a_t, h_t, z_t) in order to study the partial-equilibrium behavior of each microeconomic unit. From (10), the inverse-demand function faced by oligopolistic firms can be described as,

$$P_Q(Q | a, h, z) = \frac{\psi C(a, h, z)}{\chi Q_t},$$

and this representation is used for expressing the problem of the oligopolistic firms in a Bellman-equation form.

2.2.2 Oligopolistic firms and their necessary conditions

The problem of firm $j \in \{1, \dots, N\}$ can be written as,

$$V^j(a, h, z) = \max_{q_j, x_j \geq 0} \left\{ \frac{\psi}{\chi} \frac{C(a, h, z)}{q_j + \sum_{\substack{i=1 \\ i \neq j}}^N Q^i(a, h, z)} q_j - W_Q(a, h, z) \frac{q_j}{z} - x_j + \frac{V^j(a', h', z')}{1 + R(a', h', z')} \right\} \quad (\text{P1}')$$

subject to,

$$z' = (1 - \delta_z) z + \theta \sum_{i=1}^N X^i(a, h, z),$$

given $\{(Q^i(a, h, z), X^i(a, h, z))\}_{i=1, i \neq j}^N$, the state-dependent household demand for the perfectly competitive good, $C(a, h, z)$, a state-dependent price system $(R(a, h, z), W_y(a, h, z), W_Q(a, h, z))$, and given a law of motion for the state variables, $(a', h', z') = M(a, h, z)$.

The obvious intratemporal condition underlying the market product supply, q_j , is,

$$\frac{\psi}{\chi} \frac{C(a, h, z)}{q_j + \sum_{\substack{i=1 \\ i \neq j}}^N Q^i(a, h, z)} \left(1 - \frac{q_j}{q_j + \sum_{\substack{i=1 \\ i \neq j}}^N Q^i(a, h, z)} \right) = \frac{W_Q(a, h, z)}{z}. \quad (15)$$

The intertemporal condition is given by,

$$1 = \theta \frac{V_z^j(a', h', z') [1 + R(a', h', z')] - V^j(a', h', z') R_z(a', h', z')}{[1 + R(a', h', z')]^2}. \quad (16)$$

2.2.3 The labor demand function of perfectly competitive firms

It is straightforward to see that, due to the linear technology employed in producing good y , the labor demand function is perfectly elastic,

$$w_{y,t} = Ah_t. \quad (17)$$

2.3 National accounts

A key national-accounts identity of such a macroeconomy is,

$$c_t + p_{Q,t}Q_t = w_{y,t}l_{y,t} + w_{Q,t}l_{Q,t} + S_t d_t, \quad (18)$$

where the left-hand side is the value of *total final sales* in period- t consumer prices, whereas the right-hand side is the *sum of labor incomes plus the operating surplus* of the oligopolistic firms (profits distributed as dividends, $S_t d_t$). Using the fact that, in equilibrium, profits, $S_t d_t = p_{Q,t} \sum_{i=1}^N q_{i,t} - w_{Q,t} \sum_{i=1}^N l_{i,t} - \sum_{i=1}^N x_{i,t} = p_{Q,t}Q_t - w_{Q,t}l_{Q,t} - x_t$, (with $Q_t \equiv \sum_{i=1}^N q_{i,t}$, $l_{Q,t} \equiv \sum_{i=1}^N l_{i,t}$, and $x_t \equiv \sum_{i=1}^N x_{i,t}$, the total investment by firms), and the insight that, due to the constant returns to scale technology in the production of sector y , $w_{y,t}l_{y,t}$ should be equal to y_t , (18) becomes,

$$c_t + p_{Q,t}Q_t + x_t = y_t + p_{Q,t}Q_t. \quad (19)$$

Equation (19) is the typical national-accounts identity, consumption ($c_t + p_{Q,t}Q_t$) plus investment (x_t) equals total production ($y_t + p_{Q,t}Q_t$). What is made transparent by (19) is the fact that,

$$c_t + x_t = y_t, \quad (20)$$

i.e. the potential for investment in knowledge, $x_t > 0$, comes solely from a decision of consumers to refrain from consuming the full amount of produced y_t and, implicitly, to allow some part of this product to be used by the firms as a resource for knowledge investment.

With oligopoly in general equilibrium, households, (a) buy the goods of the firms, (b) provide labor to the firms, and (c) are also the stockholders of the firms. Oligopolistic firms make positive profits, so sales revenues (the expenditure share of household income on the firms' products) exceed production cost (the labor wages given to the household).

The two first transactions between firms and households, (a) and (b) above, generate a net deficit in the household budget constraint, $w_{Q,t}l_{Q,t} - p_{Q,t}Q_t < 0$, equal in absolute value to the *sales profits* of the firms. In the absence of any growth opportunities, a least requirement from a shareholder would be to receive the sales profits of the firms in terms of dividends, in order to break even with respect to the three transactions with the firm, (a), (b) and (c) above. But in order for firms to invest in knowledge, they need to distribute dividends which are less than the sales profits, and spend the rest in investment.

In general equilibrium, a positive knowledge investment by firms means that the transactions (a), (b) and (c) above, between households and firms, result to a net deficit in the household budget constraint. Thus, households would need to finance *indirectly* firm investment from other sources of income, like income from working in a perfectly competitive sector of the economy, as equation (20) reveals. Under what conditions would households hold such shares of oligopolistic firms? The answer to this question rests upon the incentives underlying the trading of stocks in the stock market (and, in particular, equilibrium Tobin's q for acquiring a unit of knowledge) and also upon the incentives behind human-capital investments by households, that may enable the *perfectly competitive* sector to sustain transactions (a), (b) and (c) above, with a positive knowledge investment in all periods. The

forces behind these incentives are revealed in the general-equilibrium analysis of the model below. Yet, a key factor is equity returns, or, growth in equity. Thus, before moving to the general analysis of the model, some remarks on the determinants of stock prices should be made.

2.4 Pricing equity

Substituting (18), which contains market-clearing conditions, into the budget constraint of the household, given by (6), it is,

$$S_{t+1} = S_t$$

with $t = 0, 1, \dots$. This is true since firms issue no new equity over time and with a representative household there is no trading of stocks among households over time. For this reason, the total value of shares can be normalized. By convention, it can be assumed that $S_0 = 1$ with $S_{j,0} = \frac{1}{N}$, for all $j \in \{1, \dots, N\}$, since all firms are ex-ante symmetric in period 0. Therefore, from definition (7), in equilibrium,

$$a_t = P_{S,t} , \tag{21}$$

$t = 0, 1, \dots$

In equilibrium, the price of a share should equal the present value of current and future profits. Equivalently, the value of assets held by households in each period, a_t , should equal the present value of profits by all firms. Thus the market-clearing condition for assets is,

$$a_t = \sum_{i=1}^N v^i(a_t, h_t, z_t) , \tag{22}$$

where

$$v^i(a_t, h_t, z_t) \equiv \frac{V^i(a_t, h_t, z_t)}{1 + r_t} , \tag{23}$$

for all $i \in \{1, \dots, N\}$, with $V^i(a_t, h_t, z_t)$ defined as the solution to problem (P1') in equilibrium. Rearranging (23) and imposing the market-clearing condition, (22), it is,

$$(1 + r_t) a_t = \sum_{i=1}^N V^i(a_t, h_t, z_t) ,$$

so, from (21),

$$(1 + r_t) P_{S,t} = \sum_{i=1}^N V^i(P_{S,t}, h_t, z_t) . \quad (24)$$

Substituting the definition of the interest rate, given by (9), in (24), the resulting equation,

$$P_{S,t+1} = \sum_{i=1}^N V^i(P_{S,t}, h_t, z_t) - d_t , \quad (25)$$

gives the fundamental equation for pricing shares. Moreover, (25) is the asset-market-equilibrium version of the definition of $V^i(a_t, h_t, z_t)$ in problem (P1').

Given equation (25), in order for the price of equity to grow over time, the determinants of $V^i(P_{S,t}, h_t, z_t)$ and of the dividends, d_t should also grow. These determinants are the state variables (h_t, z_t) . With growth potential for knowledge and human capital, stock-market prices can also grow over time. This potential (but perfectly foresighted) growth of stock prices gives a direct incentive to households to refrain from current consumption and to leave a key income margin, $x_t = y_t - c_t$, out of the product of the perfectly-competitive sector of the economy: this income margin, hidden in the budget constraint of the households, is the financing source for investments by firms, as equation (20) has revealed in the national-account analysis above.

2.5 General equilibrium

In general equilibrium, a vector of prices $\left\{ \left(p_{Q,t}^*, r_t^*, w_{y,t}^*, w_{Q,t}^* \right) \right\}_{t=0}^{\infty}$ and a vector of demanded-supplied quantities are such that, all microeconomic units solve their own problem for the given price vector $\left\{ \left(p_{Q,t}^*, r_t^*, w_{y,t}^*, w_{Q,t}^* \right) \right\}_{t=0}^{\infty}$ and all markets clear at the same price vector.

The equilibrium characteristics of the model are given by the following proposition.

Proposition 1

In equilibrium, the supply and investment strategies of the firms are given by,

$$q_{j,t} = \omega z_t , \quad (26)$$

$$x_{j,t} = \phi z_t , \quad (27)$$

for all $j \in \{1, \dots, N\}$, with ω given by,

$$\omega = \frac{1}{N} \frac{1 - \frac{1}{B} \left[\theta \phi N + \delta_h - \delta_z + \frac{1-\beta}{\beta} (1 + \theta \phi N - \delta_z) \right]}{1 + \frac{1-\chi-\psi}{\psi} \frac{N}{N-1}} , \quad (28)$$

the parameter ϕ solves,

$$1 + \frac{(1-\beta)(1+\theta\phi N - \delta_z)}{\beta\theta\phi} = \frac{\frac{\psi}{\chi N}}{\frac{\frac{\psi}{\chi} \left(1 - \frac{1}{N} + \frac{1-\chi-\psi}{\psi}\right) \frac{1-\beta}{B\beta} (1+\theta\phi N - \delta_z)}{1 - \frac{1}{B} \left[\theta\phi N + \delta_h - \delta_z + \frac{1-\beta}{\beta} (1+\theta\phi N - \delta_z)\right]} - 1} , \quad (29)$$

$$l_{y,t} = l_y = \frac{1-\beta}{B\beta} (1 + \theta \phi N - \delta_z) , \quad (30)$$

$$l_{Q,t} = \frac{\sum_{i=1}^N q_{i,t}}{z_t} = l_Q = N\omega , \quad (31)$$

$$e_t = e = \frac{1}{B} (\theta \phi N + \delta_h - \delta_z) , \quad (32)$$

the value of shares held by households equals,

$$a_t = \frac{N}{\theta} z_t , \quad t \geq 1 \quad (33)$$

consumption of good y is given by,

$$c_t = \frac{\frac{N}{\theta} \frac{1-\beta}{\beta} (1 + \theta \phi N - \delta_z)}{1 + \frac{\psi}{\chi} \left[\frac{1}{N} - \left(1 - \frac{1}{N}\right) \frac{l_y}{N\omega} \right]} z_t , \quad (34)$$

consumption of good Q is,

$$Q_t = N\omega z_t, \quad (35)$$

the prices are,

$$p_{Q,t} = p_Q = \frac{\frac{\psi}{\chi\theta\omega} \frac{1-\beta}{\beta} (1 + \theta\phi N - \delta_z)}{1 + \frac{\psi}{\chi} \left[\frac{1}{N} - \left(1 - \frac{1}{N}\right) \frac{l_y}{N\omega} \right]}, \quad (36)$$

$$r_t = \frac{1}{\beta} (1 + \theta\phi N - \delta_z) - 1, \quad t \geq 1 \quad (37)$$

$$r_0 = \frac{z_0}{a_0} \frac{N}{\beta\theta} (1 + \theta\phi N - \delta_z) - 1, \quad (38)$$

$$w_{y,t} = w_{Q,t} = Ah_t, \quad (39)$$

and

$$\frac{h_{t+1}}{h_t} = \frac{c_{t+1}}{c_t} = \frac{Q_{t+1}}{Q_t} = \frac{z_{t+1}}{z_t} = 1 + \theta\phi N - \delta_z, \quad t \geq 0, \quad (40)$$

whereas,

$$\frac{a_{t+1}}{a_t} = 1 + \theta\phi N - \delta_z, \quad t \geq 1, \quad (41)$$

and,

$$\frac{a_1}{a_0} = \frac{z_0}{a_0} \frac{N}{\theta} (1 + \theta\phi N - \delta_z). \quad (42)$$

Proof

[to be added]

2.6 Tobin's q

From (33) and (2), it is transparent that,

$$\text{Tobin's } q = \frac{\text{cost of a share}}{\text{cost of acquiring } z} = \frac{\frac{N}{\theta} z}{\frac{1}{\theta} z} = N. \quad (43)$$

2.7 Numerical examples

These appear in Figures 1 through 3.

The parameter values are,

$$\beta = .96, \chi = \psi = .15, B = .27, \delta_h = .03, \delta_z = .1, \text{ and } \theta = .7$$

3. A step further: matching empirical facts

In a version of the model with slightly modified preferences in order to capture higher demand elasticities for Q , the reported inverse-U relation between competitiveness and innovation is captured.

The preferences are,

$$\sum_{t=0}^{\infty} \beta^t \left\{ \chi \frac{[c_t (1 - l_{y,t} - l_{Q,t} - e_t)]^{1 - \frac{1}{\eta}} - 1}{1 - \frac{1}{\eta}} + (1 - \chi) \frac{Q_t^{1 - \frac{1}{\eta}} - 1}{1 - \frac{1}{\eta}} \right\}$$

and the numerical examples (showing the inverse-U relationship) in Figure 4 use the following parameter values,

$$\beta = .96, \chi = .3, B = .78, \delta_h = .05, \delta_z = .02, \text{ and } \theta = 1 \text{ and}$$

$$\eta = 1.5$$

4. Comparisons of concepts and mechanisms with existing growth theories

4.1 Protagonists

Under perfect competition, a large number of households, possessing a stock of some form(s) of capital and also a time endowment, rent the services of these endowments to a large number of perfectly competitive firms that operate some technology. Perfectly competitive prices formed in capital- and labor markets reflect economic primitives, pure from any strategic

interactions among firms: the pure Pareto-efficient technological potential is reflected in the prices that households take in order to decide upon investments. If anticipated prices, reflecting the whole technological potential, encourage households to save more capital and to dispose more time to production, the whole economy follows these investment decisions, going upwards. Households are the protagonists in the growth process, deciding upon how to dispose their endowments and especially how to reinvest into them. Thus, models of perfect competition imply a strong causality from household savings to growth, not found to hold in the data (see, for example, Carroll and Weil (1994) and (2000) for evidence of the reverse causality and a proposed explanation).

Romer's (1986) and (1990) pioneering studies, gave a role to firms and their investments, breaking the tight link between the Pareto-efficient technological frontier and competitive prices. In Romer (1990), the number of patents is essentially the "capital of the economy." Yet, in Romer's (1990) paper on R&D and monopolistic competition, the assumption of a fixed cost for each invention in terms of the consumable good, leaves, again, the household behavior playing the leading role in the growth process: more savings, lead to more inventions and to higher growth. The same channel from savings to growth also applies in Romer (1986).

On the contrary, in the present study, innovation depends on strategic incentives among firms and on market-power concentration. Households play a number of *secondary* roles in the investment and growth process, *following* the decisions of firms: they demand the good of the firms, they supply labor to the firms (who act as oligopsonists of labor), and they demand the firms' shares. It is firms that possess the way of adding to the stock of knowledge and do so only for the profit-maximizing goals of the firm, and to the extent that market conditions indicate that it is profitable. Yet, only when dividend growth and stock-value appreciation opportunities are significant, households decide to invest more and consume less, restricting

themselves to a secondary, follower role in the macroeconomic growth process.

In the model of this study, unlike Ramsey-type models, the Rebelo (1991) -type of endogenous linear-growth models, and the externalities Romer (1986) framework and the endogenous-technical-change approach by Romer (1990), capital and the numeraire consumption good are not ex-ante tradable at a fixed price. With stock markets modeled explicitly, acting as an intermediary between firms' direct and tangible investment choices and the value of capital claims, it is Tobin's q that determines the relationship between one unit of knowledge invested by the firm and the price of the numeraire consumption good. Ex post, in a perfect-foresight general equilibrium without any frictions, investment is efficiently allocated by markets, and Tobin's q is greater than one.

4.2 A dichotomy

Both the neoclassical and the new growth theory have the element of the following dichotomy: technology, the supply side, sets a growth possibilities frontier, subject to the market structure and possible externalities in production. Households, the owners of all endowments, capital and time, choose a savings strategy according to their ex-ante intertemporal consumption allocation preferences that reflects their preference for utilizing a certain growth possibilities frontier.

In the sense that the preference frontier induces consumer choices for intertemporal allocation of consumption, both the neoclassical and the new growth theory are supply-side approaches to growth. However, because of the predominant savings choice by households, there is a direct causality between savings and growth. For example, in the book by Jones (2000), all growth theories have been analyzed adequately using an exogenous savings rate. This was possible to do, because in all these theories, there is some exogenous ex-ante *intra-temporal* trading price between capital and a numeraire consumable good. The heart of

the theories presented in Jones (2000) is to endogenize *intertemporal prices*, namely interest rates, which reflect the growth possibilities frontier. When consumer optimization is also present, as in the presentation of these theories by Barro and Sala-I-Martin (1995), these intertemporal prices induce consumer choice and growth rates can also vary according to some differences in consumer preferences.

In neoclassical and new growth theory, due to the fact that, ex-ante, consumables and capital can be traded at fixed, pre-specified prices, the models can be placed ex-ante and analyzed in the consumption commodity space, with the raw preference primitives being a separate, powerful factor in determining the growth choice. The model of this paper cannot fit ex ante in the consumption commodity space before it is fully solved as a game: there is more action, because, given a market structure, without resolving the oligopolistic game among firms, the role of primitives (and especially of preferences) cannot be revealed.

Why the approach of this study is not subject to the neoclassical and new-growth theory dichotomy between the supply side, reflecting the economy's technological advance and growth possibilities, and the choices by a thrifty consumer who picks a best-preferred growth rate? In the theory stressed in this paper, there is no ex-ante (exogenously set) *intratemporal* trading price between capital and a numeraire consumable good: this price is endogenous, depending on firms' choices according to stock-market trading and Tobin's q (which is endogenous) and, above all, depending on household preferences over a good traded in perfectly competitive prices and a good supplied by oligopolists. The joint determination of both the *intratemporal* and the *intertemporal* prices of all goods is what breaks the dichotomy of a supply-side determined growth possibilities frontier, that has the household acting as the protagonist in choosing the development path of the economy. In the present study, it is left to firms and industrial organization to be the protagonists of growth.

Romer's (1990) approach does analyze the stock-market value of ideas, but most action stays on the supply side: monopolistic firms provide ideas as intermediate goods to perfectly competitive firms (which are on the supply side, too), while the cost of an invention is a fixed predetermined intratemporal price in terms of a consumable good. It is again, left to the consumer to make the key decisions and consumer choice between consumption today and more capital tomorrow under a fixed, pre-specified price for trading these consumption with capital/knowledge assets today. Therefore, the dichotomy remains.

4.3 A suggested synthesis

Developing any kind of “to know how” is a highly specialized task that is typically undertaken by firms. But who finances knowledge investment? Directly, the cost of acquiring knowledge is financed by the firms at prices of the consumer basket. Indirectly, these investments are financed by the households that hold the firm equity. If Tobin's q is higher than one, it is more expensive for a household to finance this investment, it buys it at Tobin's q . This happens because the firms know how to acquire knowledge, useful for their profit-maximizing purposes.

Related models stressing IO aspects of growth are these by Aghion et. al. (2002) and Klette and Kortum (2002). They both focus on modeling patents and on the introduction of new (final or intermediate) goods, or on quality improvements. This might be a very promising direction for studying the behavior and role of oligopolies in general equilibrium.

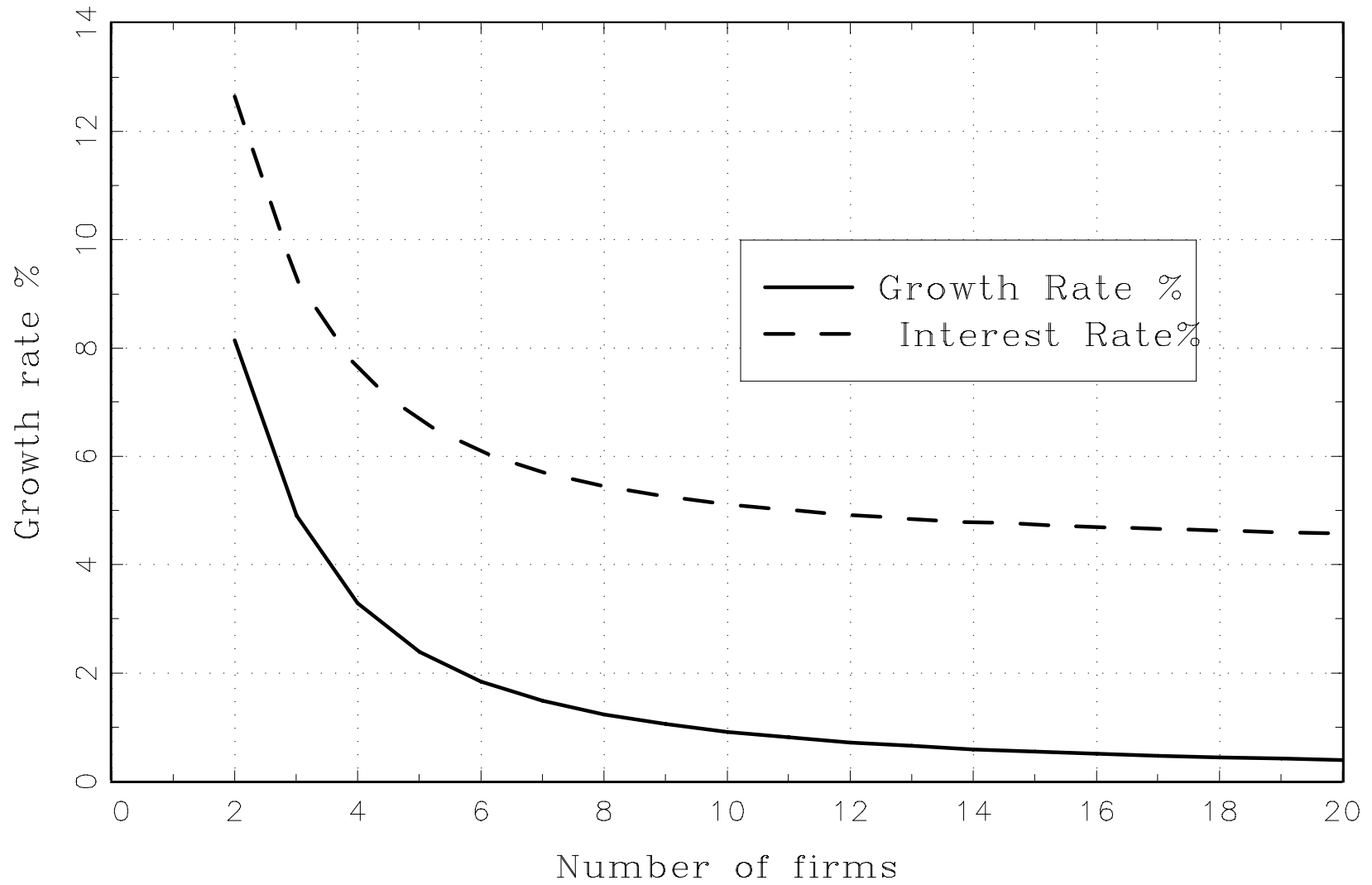
This study suggests a complementary direction, this of continuous investments aiming at increasing the rate of incremental technological progress. Moreover, it suggests that the key to studying the role of industrial organization for growth, is the explicit modeling of stock markets and the conditions under which households can sustain the investments undertaken by firms. This might be a useful angle from which the growth researcher can look at the

sources of endogenous economic development. A synthesis of analyzing cost innovations together with the pursuit of firms for patents, might open better questions to ask about IO and macroeconomic growth. In particular, the link between firm investments in knowledge and the stock-market value of their equity seems to be an interesting topic to investigate both empirically and theoretically.

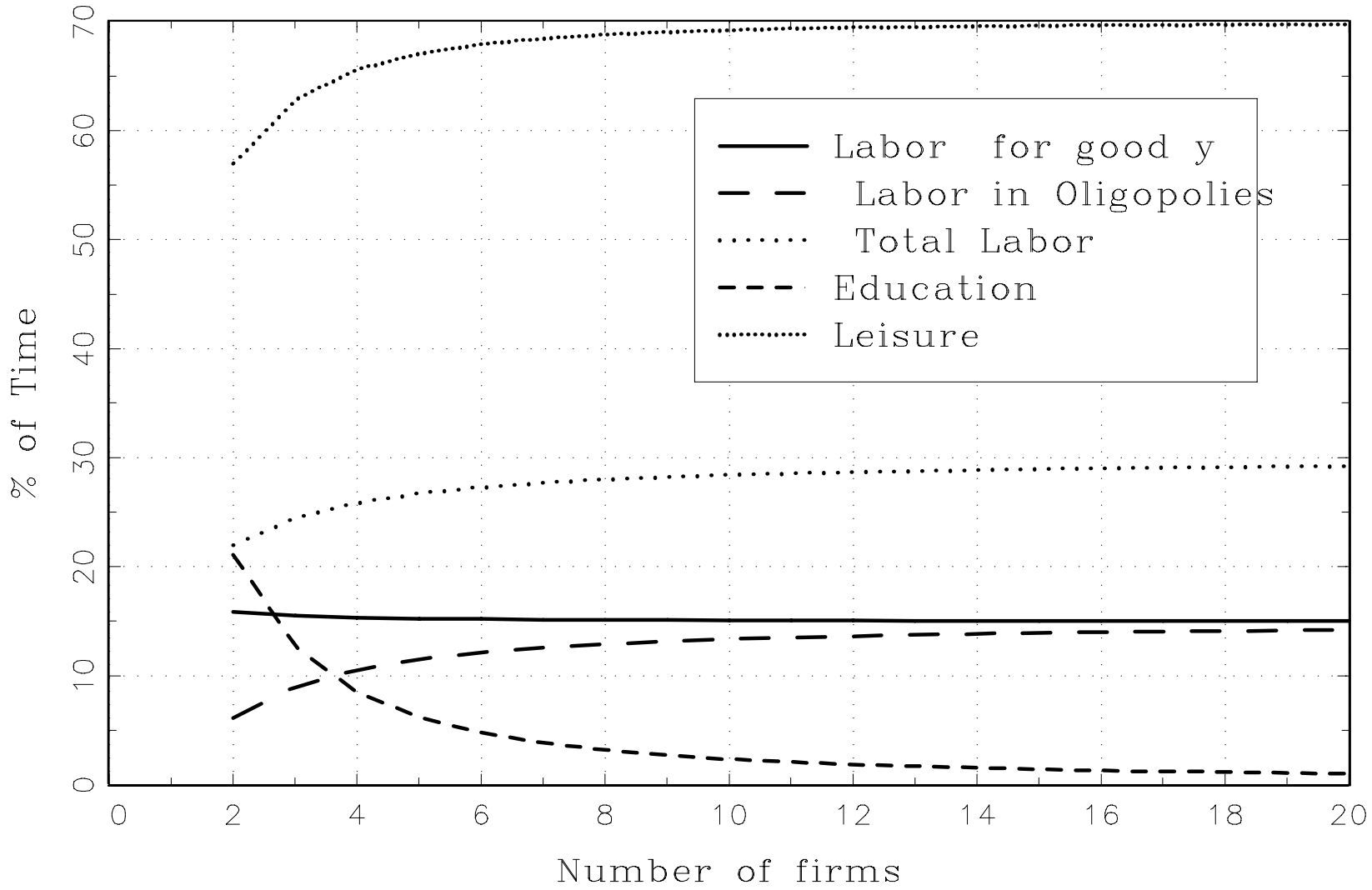
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Growth rate & Stock-market Rate of Return as functions of N



% of Time Devoted to Work, Education, and Leisure



Investment and Sales Profits as % of GDP – Plowback Ratio

