Time, Quality, and Growth

Francisco Alcalá*

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Abstract

Consumption requires time (consumption and time are complements). Also, higher-quality goods provide more utility per unit of time allocated to consumption, though at a higher monetary cost. Since time is limited, higher income is decreasingly spent augmenting the number of units of goods being consumed and increasingly spent in upgrading their quality. After analyzing the basic microeconomics of this process, the paper investigates its implications for the nature of GDP growth. As a country develops, raising the quality of output becomes increasingly important as a component of GDP growth relative to quantity growth. Furthermore, technological progress is increasingly quality-biased. The paper also explores the potential role of progressive consumption taxes as a growth policy.

Keywords: Growth, Product Quality, Allocation of Time, Technical Progress, Learning by Doing.

JEL Classification: O11, O15, O33.

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1 Introduction

Consumption requires time. You need time to listen to a concert, travel for pleasure, or play with a game console. Since time is limited, this reduces the possibility of increasing utility by increasing the quantity of consumption (i.e., by increasing the number of units of goods being consumed). On the other hand, higher-quality goods provide higher utility per unit of time allocated to consumption, though at a higher monetary cost. The consequence of these facts is that higher income is decreasingly spent augmenting the number of units of goods being consumed and increasingly spent upgrading their quality. This paper analyses the basics of this consumer decision and shows that it has important implications for growth across different stages of development. Specifically, the paper explores three issues in a simple macroeconomic framework: the increasing importance of the quantity upgrading component in GDP growth; the possible quality bias of technological progress; and the consequences of progressive consumption taxes on growth (i.e., higher taxes on higher-quality goods).[1]

The macroeconomic implications of the consumer's quality/quantity decisions investigated in the paper are motivated by empirical evidence in several areas. First of all, there is increasing evidence of the importance of quality growth as a component of GDP growth (even if measuring this component is a very complicated endeavor). For example, the Boskin Commission Report (1996) argued that unmeasured quality change was the most important source of CPI upwards bias in the US and would be responsible for an approximate effect of 0.6 percent per year. Bils and Klenow (2001) estimate that annual quality growth averaged 3.7 percent for consumer durable goods in the US over 1980-1996 (about 60 percent of this growth would have been wrongly accounted for as inflation by the US Bureau of Labor Statistics). In turn, Bils (2005) estimates an annual quality growth for durables of at least five percent over 1988-2005.[2]

However, the importance of quality growth as a component of GDP growth seems to have been increasing through time, since backwards extrapolation of recent estimations of quality growth and CPI bias would result in very improbable levels of consumption in previous centuries. According to Gordon (2005): "While the CPI may have overstated inflation in the mid-1990s by about one percent per year, as concluded by the Boskin Commission, it does not make sense to extrapolate

[1] For the implications of this framework on the effect of inequality on growth (inequality affects the quantity/quality composition of output and this in turn affects learning by doing and technical progress), see Alcalá (2008).

[2] The literature on the upward bias in the measurement of CPI inflation due to unmeasured quality growth is extense. For example, Gordon (2006) estimates that, even after the thorough methodological revisions recently put in place by the BLS, there is still an upward bias in the measurement of CPI annual inflation of at least one percent point, which is due to a large extent to unmeasured quality upgrading. See also Shapiro and Wilcox (1996), Gordon (2005), and Bils and Klenow (2001) and Bils (2005) for further references.

that rate of bias backwards over long periods of time. The "Hulten-Bruegel paradox" shows that any such exercise in backward extrapolation yields levels of real consumption two or four centuries ago that are implausibly low, barely providing an average household with a pound of potatoes per day, with nothing left over for clothing or shelter. The paradox raises the possibility that at some point in the past price index bias, at least for some important products, may have been zero or negative rather than positive."

International trade also provides relevant evidence for this paper. The recent trade literature emphasizes the importance of the quality dimension in describing the current patterns of international trade. Horizontal specialization across goods is losing importance relative to vertical (quality) specialization within goods. In particular, richer countries tend to specialize in exporting higher quality goods (Schott 2004, Hummels and Klenow 2005). A possible explanation for the comparative advantage of richer countries in producing higher-quality goods is that these goods tend to be more intensive in physical and human capital. Complementary to this explanation is that richer countries use more advanced technologies and that technological progress tends to be quality biased. On the demand side, richer countries tend to import relatively more from countries that produce higher-quality goods (Hallak 2006), which is consistent with the positive relationship between income and the demand for quality.

Most models that take into consideration the quality dimension of goods typically assume a positive relationship between income and the demand for quality. This positive relationship is taken as a fact without exploring the possible existence of some fundamental reasons for it. This paper shows that the positive relationship between income and the demand for quality can be explained as a consequence of the complementarity between consumption and time, and the consumer's time constraint.[3] The implications of the complementarity between consumption and time have received very little attention in spite of the early work by Becker (1965).[4] In particular, the connection between the time constraint and the demand for higher-quality goods seems to have been completely neglected. The argument in this paper can be expressed as follows. Consider both

[3] The effect is reinforced by the possibility of satiation. Note that satiation is linked to quantity but not to quality. For example, the average individual in a developed economy would probably not increase the number of meals per day, should the price of food and restaurants go to zero. However, it is unlikely that he would not patronize more frequently the best restaurants in the country, should their prices go to zero. In other words, quality upgrading is also the response to income rises in the case of goods where there is satiation.

[4] There are important exceptions, however. Goolsbee and Klenow (2006) have analyzed consumer decisions with respect to goods whose main cost is the time spent on their consumption (e.g., watching TV and using the Internet for fun). In turn, Hall and Jones (2007) show that if the marginal utility of consumption is decreasing, consumers will spend an increasing share of income on extending life expectancy, as they get richer. The underlying reason is similar to the starting assumption in this paper: individuals need time to obtain utility.

the time and monetary costs of obtaining utility through consumption. Since time has a higher monetary value to richer individuals and quality saves time to obtain utility, consuming higher-quality goods provides relatively cheaper utility to richer individuals. Hence richer individuals consume higher quality.

The main points can be made with a representative-agent model with a single good that is produced along a continuum of quality varieties. Since the paper aims at carrying out the analysis in a framework as simple and tractable as possible, this is the framework being adopted. The paper analyzes first the basics of consumer quantity/quality decisions in a partial equilibrium context. Then, the analysis is embedded into a growth model in order to investigate its implications for the nature of GDP growth along different stages of development. The natural implication of consumer behavior in this context is that, as a country develops, raising the quality of output becomes increasingly important as a component of GDP growth, relative to quantity growth. This is is consistent with the large importance of quality growth that has been estimated recently and the unlikeliness that these estimates could be extrapolated backwards. Then, the paper investigates growth from the point of view of its sources, assuming a two-dimension learning-by-doing process.[5] The model predicts that technological progress is increasingly biased in favor of reducing the production costs of higher-quality goods. Again, this is consistent with the evidence showing that richer countries have a comparative advantage in producing higher-quality goods. Finally, the paper analyzes the potential role of progressive consumption taxes as a growth policy. Since the most important limitation for technical progress at early stages of development is reaching a large scale of production, growth can be enhanced by shifting the quantity/quality composition of GDP in favor of a larger scale. Growth is therefore enhanced at early stages of development by charging higher taxes on higher-quality goods.

The paper is organized as follows. The partial equilibrium analysis of the consumer's quantity/quality decisions is carried out in Section 2. Section 3 embeds this analysis into an exogenous-technological-change growth model. It explores the quantity/quality nature of GDP growth along different stages of development. Technological change is endogenized in Section 4 assuming a two dimensional learning-by-doing process in a model where technological progress can be quality biased. This section also explores the potential role of progressive consumption taxes as a growth policy. Section 5 summarizes and concludes. The final Appendix shows how the model can be recasted as a model where higher-quality goods are defined as goods with a larger set of characteristics.[6]

[5] The paper in the growth literature most closely related to this one is probably Stokey (1991). This is a pioneering paper introducing the quality dimension into an endogenous growth model that focus on the private incentives for human capital accumulation.

[6] See Stokey (1988) and (1991) for outstanding examples of this type of models.

2 Time to Consume and the Preference for Quality

This section analyzes the basic microeconomics of quantity/quality consumption decisions in a partial equilibrium framework. The analysis takes prices and income as exogenous. Before considering different qualities, it will be useful to consider an economy with only one good and only one quality, and where consumption and time are complements, in order to clarify the main assumptions in the analysis.

2.1 One Good and a Single Quality

Utility depends on the number of units x being consumed and the time allocated to their consumption. The more time that is allocated to consuming a given unit of a good, the more utility it provides. Moreover, the time allocated to the consumption of each unit of consumption is the same for all units.[7] Time per unit of consumption is denoted by ω. , according to the following utility function:

$$U = U(x, \omega); \tag{1}$$

$$U_x > 0, U_\omega > 0; \quad U_{xx} \leq 0, U_{\omega\omega} \leq 0, U_{x\omega} \geq 0.$$

Subscripts on U indicate partial derivatives. Total time allocated to consumption is taken as exogenous and normalized to be equal to 1.[8] Normalize the price of the single good to be equal to 1 and denote income by y. Consumers maximize (1) subject to the income and the time for consumption constraints:

$$x \leq y; \tag{2}$$

$$1 = x \cdot \omega; \tag{3}$$

$$x \geq 0, \quad q \geq 0. \tag{4}$$

I consider the following assumption on the utility function:

Assumption A.1 $\lim_{x\to 0} U_x - \frac{1}{x^2}U_\omega > 0, \quad \lim_{x\to\infty} U_x - \frac{1}{x^2}U_\omega < 0, \quad \frac{d}{dx}\left(U_x - \frac{1}{x^2}U_\omega\right) < 0.$

[7] This assumption could be derived from a framework where the consumer chooses how much time to allocate to the consumption of each unit of the good, and where the marginal utility of the time allocated to each unit of consumption is decreasing.

[8] The complementarity between consumption and time has important implications for the allocation of time between work and leisure (or consumption). For example, in the case of consumption and time being perfect complements, higher wage would necessarily imply lower labor supply (introducing quality differentiation opens then the possibility of an upward sloping labor supply). However, the main points in this paper can be made without considering individuals' labor supply decisions.

To interpret Assumption A.1 note that when the consumer decides to increase the quantity of consumption, the amount of time available to the consumption of each unit decreases by $1/x^2$. Therefore, the change in utility is $U_x - U_\omega/x^2$. Hence, $\lim_{x\to 0} U_x - U_\omega/x^2 > 0$ means that if individuals are close to consuming nothing, they prefer to consume more units of the good even if this implies having less time to consume each unit. Then, note that $x \to \infty$ implies $\omega \to 0$. Therefore, $\lim_{x\to\infty} U_x - U_\omega/x^2 < 0$ implies that for a volume of consumption sufficiently large, the time allocated to consuming each unit of the good would be so small that utility would be reduced should the volume of consumption be further increased (since, correspondingly, the time allocated to the consumption of each unit would be further reduced). Condition $\frac{d}{dx}\left(U_x - U_\omega/x^2\right) \leq 0$ ensures that the drop of $U_x - U_\omega/x^2$ from strictly positive to negative occurs monotonically.[9]

First order conditions and (3) bring about the following equilibrium condition:

$$xU_x = \omega U_\omega; \tag{5}$$

For any y, Assumption A.1 insure that this condition characterizes an optimal quantity of consumption $x^* = x^*(y)$ (and a per-unit of consumption time $\omega^* = 1/x^*$) such that $0 < x^* \leq y$. Furthermore, there exists $\overline{x}$ such that $\lim_{y\to\infty} x^*(y) = \overline{x}$; where $\overline{x}$ solves $U_x(\overline{x}, \frac{1}{\overline{x}}) - \frac{1}{\overline{x}^2} U_\omega(\overline{x}, \frac{1}{\overline{x}}) = 0$.[10]

2.2 A Continuum of Qualities

Let us now introduce quality. There is one good in the economy which can be produced along a continuum of quality varieties $q \in [0, \infty)$. As before, consumption takes time and the more time that is allocated to consuming a given unit of the good, the more utility it provides. A higher-quality variety provides more utility than a lower-quality variety when allocating the same amount of time to its consumption. The time allocated to consumption is taken as exogenous and normalized to be equal to 1 and the time per unit of consumption is denoted by ω. Thus, utility depends on the number of units x being consumed, their quality q, and the per-unit of consumption time ω. I simplify by considering utility functions of the form $U(x, \omega) + V(q)$, where $U(x, \omega)$ is exactly the

[9]Note that the sign of $\frac{d}{dx}\left(U_x - U_\omega/x^2\right)$ is the same as the sign of $\frac{d}{dx}\left(xU_x - U_\omega/x\right)$, and that

$$\begin{aligned} \frac{d}{dx}\left(xU_x - U_\omega/x\right) &= U_x + xU_{xx} - xU_{x\omega}\frac{1}{x^2} + U_\omega\frac{1}{x^2} - \frac{1}{x}U_{\omega x} + \frac{1}{x}U_{\omega\omega}\frac{1}{x^2} \\ &= -\left(\left[\rho_x - 1\right]U_x + \left[\rho_\omega - 1\right]\frac{1}{x^2}U_\omega + (\omega + x)U_{x\omega}\right). \end{aligned}$$

Where $\rho_h \equiv -hU_{hh}/U_h$, $h = x, \omega$. Thus, a set of sufficient conditions for $\frac{d}{dx}\left(U_x - U_\omega/x^2\right) \leq 0$ is $\rho_x \geq 1$ and $\rho_\omega \geq 1$.

[10]Thus, the individual may look to be satiated even if the problem is not satiation in the good but the time constraint. For example, most individuals are not satiated by the number of movies they watch, even if their demand for movies is income inelastic. Their problem is that they do not have time to watch more movies.

same function as in the previous subsection:[11]

$$W(x,\omega,q)=U(x,\omega)+V(q) \tag{6}$$
$$V_q>0;\quad V_{qq}<0.$$

In addition to A.1, I will also consider the following assumptions:

Assumptions A.2 $\rho_x\equiv -xU_{xx}/U_x>1$; $\rho_\omega\equiv -\omega U_{\omega\omega}/U_\omega>1$; $\rho_q\equiv -qV_{qq}/V_q>0$ is bounded from above.

Individuals maximize (6) subject to

$$y=x\cdot p(q); \tag{7}$$
$$1=x\cdot\omega; \tag{8}$$
$$x\geq 0,\quad \omega\geq 0,\quad q\geq 0. \tag{9}$$

Where $p(q)$ is price as a function of quality. By an appropriate relabelling of quality varieties and without loss of generality, we can assume the following pattern of prices:[12]

$$p(q)=e^q. \tag{10}$$

Hence, $(\partial p/\partial q)/p=1$. Thus, the relabelling of qualities is such that the quality index q of a variety is one unit higher than another variety's index if and only if its price is double.[13] Utility function (6) is assumed to have been written after this relabelling.

Taking into account (10), utility maximization yields the equilibrium condition:

$$xU_x-\omega U_\omega=V_q. \tag{11}$$

Expressions (11) and (8) determine a one-to-one relationship between x and q, which is denoted $q=\psi(x)$; $\psi(x):(0,\overline{x})\rightarrow(0,\infty)$. Derivatives in (11) yield:

$$\psi'\equiv\frac{\partial\psi}{\partial x}=\frac{x\frac{d}{dx}\left(U_x-U_\omega/x^2\right)+U_x-U_\omega/x^2}{V_{qq}}>0; \tag{12}$$

[11] Obviously, the analysis is valid for any increasing transformation of this type of utility, such as those of the form $U(x,\omega)V(q)$. An example of utility function that satisfies these conditions and that I will use below is $U=\ln(q\cdot\omega/e^{\sigma/x})$, $\sigma>0$.

[12] To see that this can be done without loss of generality, consider the original set of quality varieties to be $Q\in[0,\infty)$. Quality varieties are assumed to be labelled according to an increasing invariable preference order. Let $P(Q)$ be the price of quality Q. $P(Q):[0,\infty)\rightarrow[1,\infty)$ is assumed to be continuous, increasing, differentiable, and satisfying $P(0)=1$. Relabel varieties as $q\in[0,\infty)$ using the one-to-one increasing mapping $\phi(Q)=q$ defined as $\phi(Q)\equiv\ln P(Q)$. Hence, $Q=P^{-1}(e^q)$. Therefore, prices of each relabeled quality variety are given by $p(q)=P(P^{-1}(e^q))=e^q$.

[13] This relabelling is made here for a matter of theoretical convenience but it could also have some virtues in applied work where quality is defined following a revealed preference argument.

where the sign is implied by Assumption A.1. Hence $\psi(x)$ is strictly increasing. Moreover, since $\lim_{x\to\overline{x}}(U_x - U_\omega/x^2) = 0$ and $V_q > 0$, we have $\lim_{x\to\overline{x}} \psi(x) = \infty$. See Figure 1. On the other hand, given the individual's income $y > 0$, attainable pairs (x, q) are obtained by substituting with (10) in (7): $q = \ln(y/x)$. The schedule of attainable pairs is also drawn in Figure 1. The intersection between $q = \ln(y/x)$ and $q_t = \psi(x_t)$ (together with (8)) determines the equilibrium values (x^*, ω^*, q^*). Clearly, for any $y > 0$ we have $x^* > 0, \omega^* > 0, q^* > 0$.

Individuals allocate any increase in income between increasing the number of units being consumed and increasing their quality. That is, using (7), we have:

$$dy = p(q)dx + x\frac{\partial p}{\partial q}dq.$$

Hence, when income increases, the share of the income increase that is spent in quantity and the share spent in quality upgrading are given, respectively, by:

$$p(q)\frac{dx}{dy} = \frac{1}{1 + x \cdot \psi'}; \quad x\frac{\partial p}{\partial q}\frac{dq}{dy} = \frac{x \cdot \psi'}{1 + x \cdot \psi'}. \tag{13}$$

Where $\partial q/\partial x$ is given by (12). The following proposition conveys the message that as income rises, the share of the income rise spent in upgrading the quality of consumption is increasingly larger and eventually absorbs all the additions to income.

Proposition 1 *Consider Assumptions A.1 − A.2. For any s,* $0 < s < 1$*, there is an income level* $y(s)$ *sufficiently large such that for* $y > y(s)$*, a share lower than s of any income increase is spent in raising the quantity of consumption (i.e.,* $p(q)\frac{dx}{dy} < s$*); and, symmetrically, a share larger than s of any income increase is spent in upgrading the quality of consumption (i.e.,* $x\frac{\partial p}{\partial q}\frac{dq}{dy} > s$*).*

Proof. First note that since $\lim_{y\to\infty} x(y) \leq \overline{x}$, the budget constraint $y = xe^q$ implies $\lim_{y\to\infty} q = \infty$. Then consider $\partial q/\partial x$ in (13) which can obtained from (11) and using (8):

$$\psi' = \frac{q}{V_q}\frac{[\rho_x - 1]\,U_x + [\rho_\omega - 1]\,\frac{1}{x^2}U_\omega + 2\omega U_{x\omega}}{\rho_q} = \frac{q}{x}H; \tag{14}$$

$$\text{where } H \equiv \left[\frac{\rho_x - 1}{\rho_q} + \frac{([\rho_x - 1] + [\rho_\omega - 1])\,\omega + 2\,(U_{x\omega}/U_\omega)}{\rho_q}\frac{U_\omega}{V_q}\right].$$

Where $\rho_q \equiv -qV_{qq}/V_q$, $\rho_h \equiv -hU_{hh}/U_h$, $h = x, \omega$. Assumptions A.1 and A.2 imply that H is bounded from below above 0. Hence, expression (14) and $\lim_{y\to\infty} q(y) = \infty$ yield $\lim_{y\to\infty} x\frac{\partial q}{\partial x} = \infty$. Now, using (13), we have $\lim_{y\to\infty} p(q)\frac{dx}{dy} = 0$ (and $\lim_{y\to\infty} x\frac{\partial p}{\partial q}\frac{dq}{dy} = 1$). Therefore, since (14) is continuous, for any s, $0 < s < 1$, there is an income level $y(s)$ sufficiently large such that for $y > y(s)$ we have $p(q)\frac{dx}{dy} < s$ (and $x\frac{\partial p}{\partial q}\frac{dq}{dy} > s$). ■

Thus, in a cross section of individuals, we should observe that although richer individuals consume some additional units of the same goods, they increasingly use their larger income to consume more expensive varieties of the same category of goods.

3 The Quantity/Quality Composition of Growth

In this section I lay out an exogenous growth model to explore the quantity/quality composition of GDP growth. There is a single representative agent and a single good that can be produced along a continuum of quality varieties $q \in [0, \infty)$.

3.1 The Model

Technology Labor is the only factor of production and there are constant returns to scale to produce any quality variety. Production of higher-quality varieties requires more labor per unit of output which is given by a function $F(q)$, where $F(q) : [0, \infty) \to [1, \infty)$ is continuous, differentiable, strictly increasing, and satisfies $F(0) = 1$. Thus, output at time t, x_t, when producing quality q_t is given by

$$x_t = \frac{A_t L}{F(q_t)}.$$

where L is the labor input and A_t is a general efficiency parameter that evolves over time. The labor supply is assumed to be constant and is normalized $L = 1$. By an appropriate relabelling of quality varieties, we can assume $F(q) = e^{q/\gamma}$ without loss of generality.[14] Therefore, the production function using the relabelling for the quality varieties is given by:[15]

$$x_t = \frac{A_t}{e^{q_t/\gamma}}. \tag{15}$$

Denoting the wage at t by w_t and assuming perfectly competitive markets, prices are given by:

$$p_t(q) = \frac{e^{q/\gamma}}{A_t} w_t. \tag{16}$$

Therefore, $(\partial p_t / \partial q_t)/p_t = 1/\gamma$. In this section, technological progress is assumed to be exogenous:

$$g(A_t) = \theta > 0. \tag{17}$$

where $g(.)$ indicates growth rate of the variable in parenthesis.

[14] To see this, consider the original set of quality varieties to be $Q \in [0, \infty)$. Unit labor requirements for production are given by $F(Q)$; $F(Q) : [0, \infty) \to [1, \infty)$, $F(0) = 1$, $F' > 0$. Relabel varieties as $q \in [0, \infty)$ using the one-to-one increasing mapping $\psi(Q) = q$ defined as $\psi(Q) \equiv \gamma \ln F(Q_t)$. Hence, $Q = F^{-1}(e^{q/\gamma})$. Therefore, substituting in the production function $x_t = A_t L_t / F(Q_t)$ yields: $x_t = A_t L_t / e^{q_t/\gamma}$. Note that this is a commonly used production function in models with quality differentiation (see, for example, Flam and Helpman 1987).

[15] The Appendix also shows that this production function can be obtained from a theoretical framework where higher-quality goods are defined as goods providing a larger set of characteristics and where the production of each characteristic needs a different amount of labor.

Instantaneous Equilibrium Consider the same utility function and constraints in the previous section (6)-(7)-(8)-(9). From expressions (11) and (8) we have a relationship

$$q_t = \psi(x_t) \tag{18}$$

that is increasing (see (12)) and satisfies that $\psi(0)$ is bounded from above. Given A_t, the intersection of (15) with (18) determines the instantaneous equilibrium pair (x_t, q_t) at time t. See Figure 2. In particular, (15) determines the feasible pairs whereas (18) determines consumers' choice among those pairs. Clearly, for any $A_t > 0$ there is a unique pair $(x_t, z_t) > (0, 0)$ solving (15)-(18). Both x_t and q_t are continuous and strictly increasing in A_t.

3.2 The composition of GDP growth

Denote GDP at time t by y_t:

$$y_t \equiv x_t p_t(q_t).$$

Therefore, GDP growth at the constant prices for each quality variety $p_t(q)$ is given by:

$$g(y_t) = g(x_t) + \frac{\partial p_t(q)/\partial q_t}{p_t(q)} \dot{q}_t$$

Since the elasticity of $p_t(q)$ with respect to q is equal to $1/\gamma$ (expression (16)), using (15) yields:

$$g(y_t) = g(x_t) + \frac{q_t}{\gamma} g(q_t) = g(A_t) = \theta. \tag{19}$$

This expression decomposes GDP growth into a quantity and a quality components. Using it, we can analyze the different nature of GDP growth at different stages of development. From (13) and (19) we have

$$g(x_t) = \frac{1}{1 + x_t(\partial q_t/\partial x_t)} g(y_t). \tag{20}$$

Moreover, note also that we can normalize units of output at any point of time such that $y_t = A_t$.

Proposition 2 *Consider Assumptions A.1 – A.2. For any s, $0 < s < 1$, there is a level $A(s)$ of development in terms of technological efficiency such that for $A > A(s)$, the share of GDP growth that takes the form of quantitative growth is lower than s (i.e., $g(x_t) < s \cdot g(y_t)$). Or, symmetrically, the share of GDP growth that takes the form of quality growth is larger than s (i.e., $\frac{q_t}{\gamma} g(q_t) > s \cdot g(y_t)$).*

Proof. This proposition is an immediate implication of constant positive growth $g(A_t) = \theta$, $y_t = A_t$, and Proposition 1. As a result of constant positive growth we have $\lim_{t\to\infty} A_t = \infty$. Then $y_t = A_t$ and Proposition 1 imply, respectively, $\lim_{t\to\infty} y_t = \infty$ and $\lim_{t\to\infty} x_t(\partial q_t/\partial x_t) = \infty$.

Therefore, (20) yields $\lim_{t\to\infty} g_x(t) = 0$. Hence, eventually, quantitative growth plays no role in the composition of GDP growth. Symmetrically, we have $\lim_{t\to\infty} \frac{q_t}{\gamma} g(q_t) = \lim_{t\to\infty} g_y(t) = \theta$. Since all the variables are continuous as a function of time (or as a function of A_t), we obtain the result stated in the proposition. ■

This result is consistent with the available evidence cited in the Introduction on the increasing importance of improvements in the quality of goods as a component of GDP growth.

4 The Source of Growth: Quality-Biased Technical Progress

This section builds an endogenous growth model where technical progress comes along two dimensions: (*i*) general efficiency in producing any quality variety and (*ii*) relative efficiency in producing higher-quality goods.

4.1 The Model with Endogenous Growth

Technology I assume the same production function as before except that now both technological parameters A_t and γ_t are subject to progress due to learning-by-doing. Labor supply is assumed to be constant and normalized to be equal to 1. Thus, output at time t when producing quality q_t is given by:

$$x_t = \frac{A_t}{e^{q_t/\gamma_t}}; \tag{21}$$

As before, A_t is a general efficiency parameter, whereas γ_t governs the relative efficiency in producing higher-quality goods. Both parameters A_t and γ_t evolve over time as a result of learning by doing. In the case of general efficiency, I consider a learning-by-doing process similar to the one in Krugman (1987) and Lucas (1988):

$$\dot{A}_t = \theta_1 x_t - \delta_1 A_t; \quad \theta_1 > \delta_1 > 0. \tag{22}$$

In turn, learning affecting γ_t is linked to both the quantity and quality being produced. For example, accumulated experience in sewing shirts in a clothing factory may bring about not only a higher number of sewed shirts per unit of labor but improvements in techniques and skills to carry out more accurate and error-free seems. Or, in package delivery, accumulated experience may increase the speed of delivery and lower the probability of losses (which are quality characteristics), besides increasing the number of deliveries per worker. Repeating a task improves the speed at which it is performed and also the quality of the result. As the number of units being produced tends to zero, learning tends to zero even if the quality being produced is very high. Alternatively, if the quality being produced is low, the development of specific knowledge and abilities useful to produce higher quality will tend to be very limited (even if number of units being produced is very large). In other words, producing higher quality is expected to generate more quality-biased progress in skills and techniques. Thus, I assume the following process:[16]

$$\dot{\gamma}_t = \theta_2 q_t x_t - \delta_2 \gamma_t; \quad \theta_2 > \delta_2 \geq 0. \tag{23}$$

Obsolescence parameters δ_1 and δ_2 may be justified in terms of a succession of finitely lived representative agents whose skills have to be replaced.[17] At any rate, results are obtained assuming that δ_1 and δ_2 are small and, in fact, the same basic results can be obtained with $\delta_1 = \delta_2 = 0$. However, $\delta_1 > 0$ brings about the existence of a steady state with constant rates of growth that is particularly easy to work with.

Utility I now simplify by considering a particular case of the utility function in previous sections, which can deliver a closed form solution. The representative maximizes the following instantaneous utility function subject to the same constraints (7)-(8)-(9) as before:

$$U_t = q \cdot U(x, \omega) = q_t \frac{\omega_t}{e^{\sigma / x_t}}. \tag{24}$$

As in the simpler model of the previous section, expression (21) implies that perfect-competition prices are given by

$$p_t(q) = \frac{e^{q/\gamma_t}}{A_t} w_t. \tag{25}$$

Therefore, $(\partial p_t / \partial q)/p_t = 1/\gamma_t$. This, together with the first order conditions of utility maximization, bring about the following relationship between quantity and quality:

$$\frac{q_t}{\gamma_t} = \frac{x_t}{\sigma - x_t}. \tag{26}$$

4.2 Equilibrium

Instantaneous Equilibrium Define $z_t \equiv q_t / \gamma_t$. Expressions (21) and (26) can then be rewritten as:

$$x_t = \frac{A_t}{e^{z_t}}; \tag{27}$$

$$z_t = \frac{x_t}{\sigma - x_t}. \tag{28}$$

Given A_t, the intersection of (27) and (28) determines the instantaneous equilibrium pair (x_t, z_t) at time t. See Figure 3. In particular, (27) determines the feasible pairs and (28) determines

[16] See Stokey (1988) and (1991) for a similar approach where learning by doing increases effciency in producing all quality varieties.

[17] Knowledge, experience, and skills are embodied in individuals that are subjet to a life cycle.

consumers' choice among those pairs. Note that $x/(\sigma - x_t)$ is increasing in $x > 0$ with $\lim_{x\to 0} \frac{x_t}{\sigma - x_t} = 0$; whereas $\ln(A_t/x)$ is decreasing in x. Clearly, for any $A_t > 0$ there is always a unique pair $(x_t, z_t) > (0, 0)$ solving (27)-(28). Both x_t and z_t are continuous and strictly increasing in A_t. Then, given γ_t, $q_t = z_t\gamma_t$ determines output quality q_t.

GDP Growth Denote GDP at time t by Y_t:

$$Y_t \equiv x_t p_t(q_t).$$

GDP growth at time t at constant prices $p_t(q)$ is given by:

$$g(y_t) = g(x_t) + \frac{\partial p_t(q)/\partial q_t}{p_t(q)} \dot{q}_t$$

From expression (16) we have that the elasticity of $p_t(q)$ with respect to q is equal to $1/\gamma_t$. Moreover, from (21) we have

$$g(y_t) = g(x_t) + \frac{q_t}{\gamma_t} g(q_t) = g(A_t) + \frac{q_t}{\gamma_t} g(\gamma_t). \tag{29}$$

Expression (29) provides two approaches to GDP growth. From the point of view of the composition of output, GDP grows in the quantity and the quality dimensions. From the point of view of productivity, GDP grows due to technical progress in general efficiency and quality-biased efficiency. Note that there is no reason to expect $g(x_t)$ to be equal to $g(A_t)$, and $g(q_t)$ to be equal to $g(\gamma_t)$ (in fact, this is the case only in the steady state).

From (27) and the expressions above, we have:

$$g(A_t) = \frac{\theta_1}{e^{z_t}} - \delta_1. \tag{30}$$

$$g(\gamma_t) = \theta_2 z_t x_t - \delta_2. \tag{31}$$

Using (30), (3b) and (5b) yields:

$$g(x_t) = g(A_t)\frac{\sigma - x_t}{2\sigma}; \tag{32}$$

$$g(z_t) = g(x_t)\left[1 + z_t\right]. \tag{33}$$

GDP dynamics are given by (29), (30), and (31), yielding:

$$g(y_t) = \frac{\theta_1}{e^{z_t}} + \theta_2 \left(z_t\right)^2 x_t - \left(\delta_1 + \delta_2\right). \tag{34}$$

Given the learning parameter θ_1, there is an upper bound on the decay rate $\delta_1 > 0$ for the economy to survive in the long run. Non-negative growth rates of γ_t require the following assumption:

Assumption A.3 $\delta_2/\theta_2 < z(0)x(0)$.

Note that assumption A.3 involves a condition on $A(0)$. Given $A(0)$, (27) and (28) determine $z(0)x(0)$. Propositions below often assume $A(0)$ sufficiently low. Assumption A.3 can always be satisfied by setting δ_2 sufficiently low.

Steady State In the steady state, the size of output is constant whereas quality grows at a constant rate. The following proposition characterizes the steady state using asterisks to denote its values.

Proposition 3 *For δ_2 sufficiently small, the model has a unique steady state such that $A^* > 0$, $x^* > 0$, $z^* \equiv (q/\gamma)^* > 0$, $g_q^* = g_\gamma^* > 0$, $g_Y^* = (q/\gamma)^* g_\gamma^*$.*

To check this proposition, first note that $A^* > 0$, $x^* > 0$, and $(q/\gamma)^* > 0$ imply $g_A^* = g_x^* = g_z^* = 0$, $z^* > 0$, $x^* > 0$. That is, in the steady state there is constant positive GDP growth due to quality upgrading but no quantitative growth. Moreover, all technical progress is restricted to improvements in the relative efficiency of producing higher-quality goods ($g_\gamma^* > 0$). Substituting with $g_A^* = 0$ in (30) yields

$$z^* \equiv (q/\gamma)^* = \ln \frac{\theta_1}{\delta_1} > 0. \tag{35}$$

In turn, expressions (27) and (28) yield:

$$x^* = \sigma \frac{\ln(\theta_1/\delta_1)}{1 + \ln(\theta_1/\delta_1)}; \tag{36}$$

$$A^* = x^* \frac{\theta_1}{\delta_1}. \tag{37}$$

Then, $g(z_t) = g(q_t) - g(\gamma_t)$ and (31) imply

$$g_q^* = g_\gamma^* = \theta_2 z^* x^* - \delta_2. \tag{38}$$

Finally, (29) yields

$$g_Y^* = z^* g_\gamma^*. \tag{39}$$

In Figure 3 the $z = \ln(A_t/x)$ schedule shifts towards the North-East until it crosses the $z_t = x_t/(\sigma - x_t)$ schedule at point $z = \ln(\theta_1/\delta_1)$ in the steady state. Assumption A.3 is sufficient to guarantee that (31) delivers a positive GDP growth at any point of time including the steady state.

Transitional Dynamics and the Changing Nature of Technological Progress First, let us check the stability of the steady state. The system (27)-(28)-(30) can be solved independently of the rest of equations. Initial condition is A_0. For $A_0 < A^*$, the schedule (27) at $t = 0$ crosses (28) to the South-West of (x^*, z^*) in Figure 3.[18] It is easy to see that the economy converges monotonically to its steady state. Given $0 < A_0 < A^*$, (27)-(28) imply $0 < x_0 < x^* < \sigma$, $0 < z_0 < z^* = \ln(\theta_1/\delta_1)$. Then, expression (30) implies $g(A_t) > 0$. This together with expression (32) implies $g(x_t) > 0$. Then (33) implies $g(z_t) > 0$. Therefore the system converges monotonically to (A^*, x^*, z^*).

[18] Equilibrium is also stable from $A_0 > A^*$ but this case does not seem to be interesting in a growth model.

Now we can analyze the different source of GDP growth at different stages of development. Early stages of development are characterized by a level of general efficiency A close to zero.

Proposition 4 *Consider the source of GDP growth from the point of view of the type of technical progress. At early stages of development, growth is mostly driven by quality-neutral progress in efficiency (g_A). However, technical progress becomes increasingly quality-biased through time (i.e., the component g_γ is increasingly important) .*

Proof. First consider the instantaneous equilibrium at initial stages of development which are characterized by $A(t)$ close to zero. Note that $\lim_{A_t \to 0} g(A_t) = \theta_1 - \delta_1 > 0$, $\lim_{A_t \to 0} z_t = 0$, $\lim_{A_t \to 0} x_t = 0$, $\lim_{A_t \to 0} g(\gamma_t) = \lim_{A_t \to 0} \theta_2 z_t x_t - \delta_2 \leq 0$, and that growth rates are continuous in time. Therefore, for $A(t)$ sufficiently close to zero we have $g(A_t) > g(\gamma_t) > z_t g(\gamma_t)$. Therefore, from expression (34) we have that, at early stages of development, quality-neutral technological progress g_A is the main source of growth.

Now consider later stages of development. Recall that z_t increases monotonically to its steady state. Hence expression (30) implies that $g(A_t)$ decreases monotonically from $g_A(0) > 0$ to $g_A^* = 0$. On the other hand, since z_t and x_t increase monotonically towards their steady state values, (31) implies that $z_t g(\gamma_t)$ increases monotonically towards $z_t^* g_\gamma^*$ which is strictly positive (assumption A.3 is a sufficient condition for $g_\gamma^* > 0$). ■

4.3 A Numerical Illustration

In this subsection I show that this framework may deliver reasonable long run paths for GDP growth.[19] Neoclassical models predict decreasing growth rates, whereas endogenous growth models of the AK type predict constant rates. However, the secular pattern of growth in advanced economies since the industrial revolution has been one of an increasing rate of growth that has tended to stabilize in the last century somewhat below 2−percent. For example, estimates of output per worker growth in England at the beginning of the ninetieth century go from 0.35−percent to 1.3−percent (see Feinstein 1981 and Crafts and Harley 1992). On the other hand, US growth in the last decade has averaged about 1.7−percent (though, as discussed in the Introduction, it is likely that it is underestimated due to non-measured quality growth). The model is discretized and calibrated to start from a GDP growth around the mean estimate of the cited interval for the beginning of XIXth century England and to yield a steady state GDP growth of 1.8−percent. Since skills and knowledge are embodied in individuals, annual depreciation rates $\delta_1 = \delta_1 = 0.025$ seem

[19] Although the stripped-down simplicity of the technical progress functions prevents obtaining plausible decompositions between quantity and quality growth.

reasonable. Furthermore, I use the following set of parameters: $\sigma = 3$, $\theta_1 = 0.054$, $\theta_2 = 0.048$. Finally, the initial value A_0 is chosen such that $x_0 = 1$. Figure 4 draws annual rates of growth of GDP for the first 300 years. GDP growth starts at an annual rate of $0.72-$percent. It then shows a rapid acceleration, doubling after 120 years and surpassing $1.68-$percent after 150 years.

GDP growth is also decomposed in Figure 4 into the quantitative growth component, $g(x_t)$, and the quality growth component, $z_t g(x_t)$. Consistent with Proposition 3, quantitative growth is the main source of growth at initial stages. Then, it is gradually substituted by quality growth. Although an empirical estimate of the path of the quality component in secular GDP growth does not yet exist, its path in Figure 4 seems implausible. It would be necessary to introduce more flexible functional forms on technical progress in order to obtain more reasonable paths. Still, an empirical assessment on the secular paths of these two components is pending.

4.4 Growth Policy: Consumption Taxes

Progressive consumption taxation (i.e., taxing luxury goods at higher rates) has been discussed from different perspectives such as the analysis of aggregate saving and the distribution of wealth.[20] In this section I discuss its possible role as a growth enhancing policy. In this model, taxation of luxury (higher-quality) goods is not only harmless to growth but may enhance it at early stages of development. Note that producing different quantity/quality combinations of output gives rise to different technical progress externalities (in terms of their quality bias). Moreover, the value of quality-biased technical progress changes along different stages of development since the quality of individuals' consumption is increasing in time. Distortionary consumption taxes (or subsidies) can be used to influence the quantity/quality combinations of output in order to favor the most valuable combination of externalities at each level of development.

At any point of time t, the government can influence the pair (x_t, z_t) (implying a value of q_t) within the feasible pairs given by (27), by using a non-linear tax/subsidy scheme. Denote after-tax/subsidy prices by $p_\tau(q,t)$. Consider the following non-linear tax/subsidy scheme parameterized by $\tau > 0$: $p_\tau(q,t) = [p(q,t)]^\tau$. Note that $\tau > 1$ involves a tax/subsidy scheme relatively unfavorable to the higher price (quality) goods, whereas $\tau < 1$ involves a scheme relatively favorable to these goods. Consumers are assumed to finance these subsidies or receive the yields of the tax scheme in a lump sum.

[20] See for example Fisher and Fisher, 1943; Friedman, 1943; Kaldor, 1955; Bradford, 1980; Courant and Gramlich, 1984; Seidman, 1997; McCaffrey, 2002; and Frank, 2005.

Production function (27) together with the assumption of perfect competition yields:

$$p_\tau(q,t) = \eta \left[\frac{e^{q_t/\gamma_t}}{A_t} w_t \right]^\tau . \tag{40}$$

After substituting into the income constraint and maximizing utility, expression (28) now becomes:

$$z_t \tau = \frac{x_t}{\sigma - x_t}. \tag{41}$$

This expression together with (27) determines the new instantaneous equilibrium. Taking derivatives, this yields:

$$\frac{dz_t}{d\tau} = \frac{x_t\left[\sigma - x_t\right]}{\sigma\left[\partial x_t/\partial z_t\right] - \tau\left[\sigma - x_t\right]^2} < 0; \tag{42}$$

where expression (27) implies $\partial x_t/\partial z_t = -x_t$. Therefore, as expected, tax/subsidy schemes relatively unfavorable to higher quality goods reduce the quality of consumption and increase quantity. This can be used to affect growth: at stages where the most effective learning is linked to reaching a scale of output as large as possible, reducing the demand for quality may be positive for GDP growth. The opposite will be true if at some point the most socially profitable learning is linked to producing higher quality.

The GDP growth effect of a tax/subsidy scheme τ can be analyzed by considering its effects on $g(A_t)$ and $g(\gamma_t)$. From (29) and using (28)-(30)-(31), we have:

$$\frac{dg(y_t)}{d\tau} = \left[\frac{dg(A_t)}{dz_t} + z_t\frac{dg(\gamma_t)}{dz_t} + g(\gamma_t)\right]\frac{dz_t}{d\tau} = \left[-\frac{\theta_1}{e^{z_t}} + \theta_2\sigma\frac{(z_t)^2}{1+z_t}\left[2 - z_t\right] - \delta_2\right]\frac{dz_t}{d\tau}. \tag{43}$$

As already seen, a tax scheme that imposes higher tax rates on higher-quality goods increases the scale of production but reduces its quality. Thus, it is always positive for $g(A_t)$, although it may have an uncertain effect on $g(\gamma_t)$. The relative effect of these two (possibly opposite-sign) effects, as well as their size relative to $g(\gamma_t)$, change over time. Early stages of development are characterized by a low general efficiency A_t, resulting in an output consumption x_t close to zero and minimal quality. Increasing the scale of output at these stages brings about a sizable increase in general efficiency growth A; whereas increases in quality do not bring about much quality-biased technological progress because this would also require a large scale of output (which is hurt by increasing quality). Moreover, quality-biased technological progress is of little value because consumers have a low valuation for quality upgrading (i.e., z_t is low; recall that z is the elasticity of price with respect to quality: $z \equiv q/\gamma = (\partial p/\partial q)/(q/p)$). Therefore, a tax/subsidy scheme that shifts GDP towards lower quality but larger output has a positive effect on GDP growth. However, the positive effect of this tax scheme on $g(A_t)$ becomes weaker at later stages of development, as A_t increases. Meanwhile, the effect on $g(\gamma_t)$ may turn out negative. Hence, for some parameter values, a tax/subsidy scheme that shifts consumption towards lower quantity but higher quality may have a positive effect on GDP growth.

Proposition 5 *At early stages of development (i.e., for general efficiency A_t sufficiently low), progressive consumption taxes (i.e., $\tau > 1$) foster GDP growth.*

Proof. Consider the initial stages of development, which are characterized by A_t being close to 0. Note that $\lim_{A_t \to 0} dg(A_t)/dz_t = -\theta_1/e^{z_t} > 0$; whereas $\lim_{A_t \to 0} dg(\gamma_t)/dz_t = 0$ and $\lim_{A_t \to 0} g(\gamma_t) \leq 0$. Since $dz_t/d\tau < 0$ (expression (42)), we have that $\lim_{A_t \to 0} dg(y_t)/d\tau > 0$. Now, continuity of growth derivatives implies that at least for an initial interval of time where A_t is still sufficiently low, GDP growth increases by imposing a tax scheme $\tau > 1$. ■

It may be noted that the argument also would hold for a more general utility setting, as long as $dz_t/d\tau < 0$ holds.[21] This proposition suggests that industrialization at early stages is favored by helping the scale of production at the cost of lower quality. However, once output has reached a large scale, growth may be more effectively enhanced by favoring the quality dimension. In fact, for some parameters, a subsidy to the production of higher quality goods, $\tau < 1$, would enhance growth. This would be the case, for example, for δ_1 and δ_2 close to zero and $\ln(\theta_1/\delta_1) < 2$.[22]

5 Concluding Comments

Recent empirical work in several areas such as real GDP growth measurement and international trade has uncovered the increasing importance of the quality dimension of output. This paper explores the time-constraint foundations of the demand for quality and some of its macroeconomic implications. The starting point is that time and consumption are complements, and that higher-quality goods provide higher utility per unit of time though at a higher monetary cost. It is then shown that additions to income are increasingly spent in upgrading the quality of consumption instead of increasing the number of units being consumed. The paper then investigates the implications of this behavior for the nature of GDP growth. The model provides a simple framework to analyze issues where the quality dimension of goods is relevant. Three topics receive a first-bite examination in the paper: the increasing component of quality growth in GDP growth, the possible quality bias of technological progress, and the role of progressive consumption taxes as a growth

[21] The reason is that the other elements in the proof are not the consequence of preferences but of technology. Consider, for example, utility functions delivering the first order condition $z(t)\tau = \psi(x(t))$, for some increasing function $\psi(.)$. This is the case if we use utility in expression (6) and assumption $A.1 - A.2$. This implies $\frac{dz(t)}{d\tau} = \frac{z(t)}{\psi(x(t))' \frac{dx(t)}{dz(t)} - \tau} < 0$.

[22] In that case, $z^* < 2$. The argument is completed using (43) and substituting with (35)).

policy. In spite of its bare-bones structure, the endogenous growth model in the paper can deliver reasonable secular paths for GDP growth of advanced economies, although it seems to largely overestimate the quality component of GDP growth. Building and calibrating a more flexible model that can match the quantity and quality components of long run GDP growth –as more thorough estimates of these components become available– seems a very interesting area for future research.

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6 Appendix: Higher-Quality Goods and the Set of Characteristics

There is a literature defining higher-quality goods as goods with a larger set of characteristics. Stokey (1991) is a pioneering growth model within this approach. In this Appendix I introduce a simple production function within this approach and show that it can be assimilated to production functions (15) and (21) in the main text. Furthermore, the setting in this Appendix introduces a distinction between intermediate goods and consumption goods (with varying sets of characteristics). This distinction may provide the grounds for additional empirical predictions such as the hypothetically decreasing share of basic intermediate goods (e.g., steel, basic chemicals, or lumber) in total GDP.

Consider an economy where there is a consumption good which can be produced along a continuum of quality varieties $q \in [0, \infty)$ and an intermediate good. Varieties of higher quality provide a larger set of *characteristics*, which are indexed by j; $j \in [0, \infty)$. Producing one unit of the good with quality q requires one unit of the intermediate good and a measure q of characteristics uniformly distributed in the interval $j \in [0, q]$. In turn, producing one unit of the intermediate good requires $1/A_t$ units of labor; whereas producing one unit of characteristic j requires $e^{j/\gamma_t}/(A_t\gamma_t)$ units of labor (thus, characteristics are indexed according to the increasing amount of labor needed to produce them). Hence, the cost of producing one unit of good with quality q at time t (which is equal to its price) is:

$$p_t(q) = \frac{w_t}{A_t}\left[1 + \int_0^q \frac{e^{j/\gamma_t}}{\gamma(t)}dj\right] = \frac{e^{q/\gamma_t}}{A_t}w_t. \tag{A.1}$$

This expression corresponds to expressions (10) and (25) in the main text.

A possible interpretation of the nature of the intermediate input is as a raw material or basic input (such as steel, wood, or concrete). Under this interpretation, the model would predict that the share in GDP of these basic inputs decreases as countries develop.

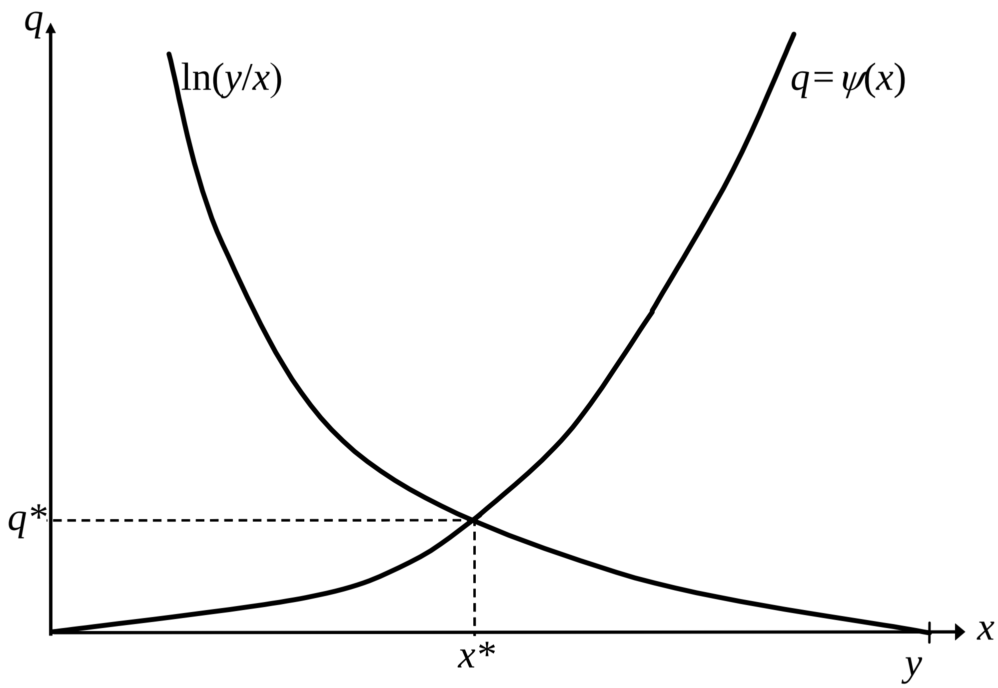

Figure 1

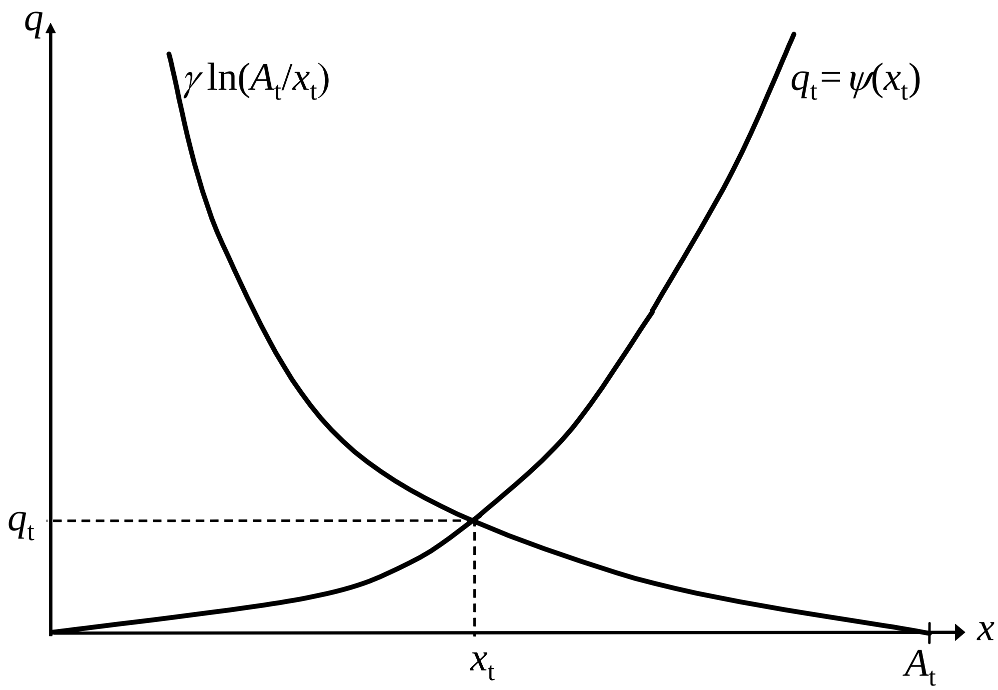

Figure 2

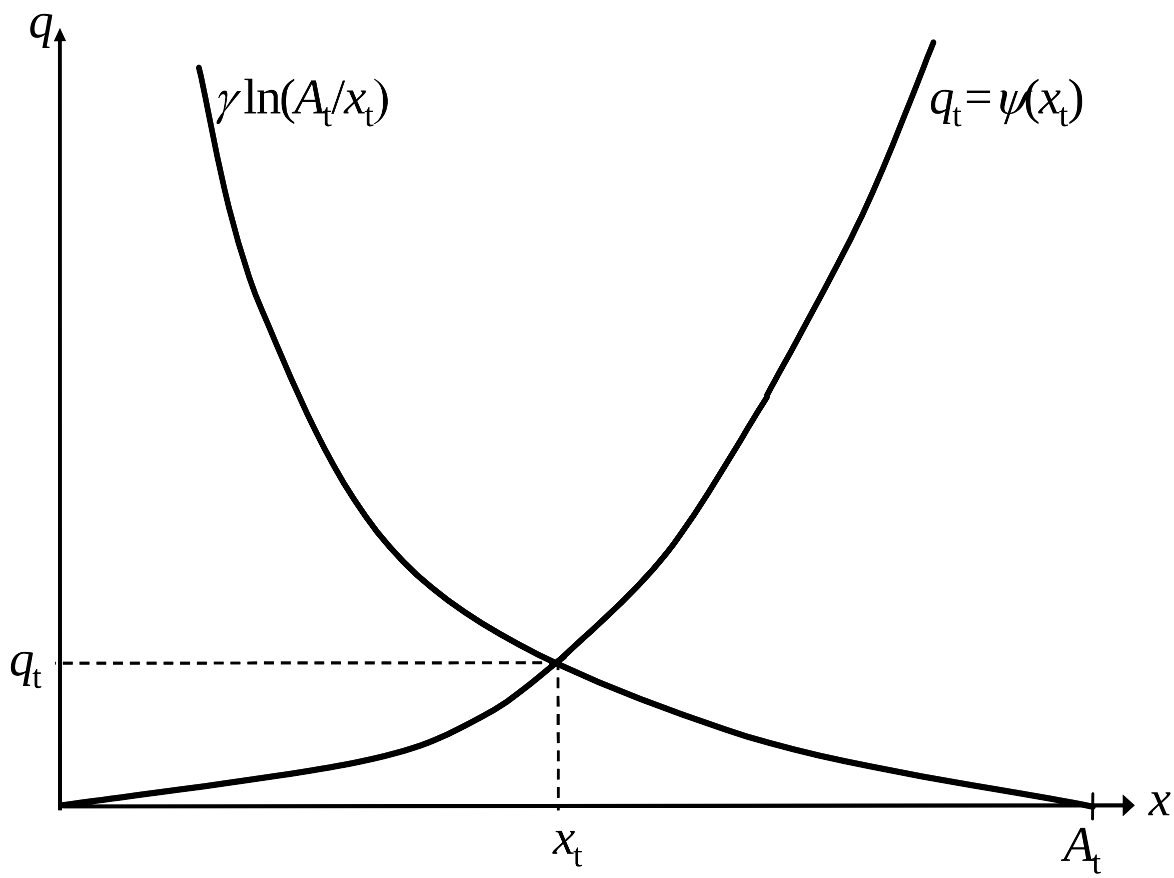

Figure 3

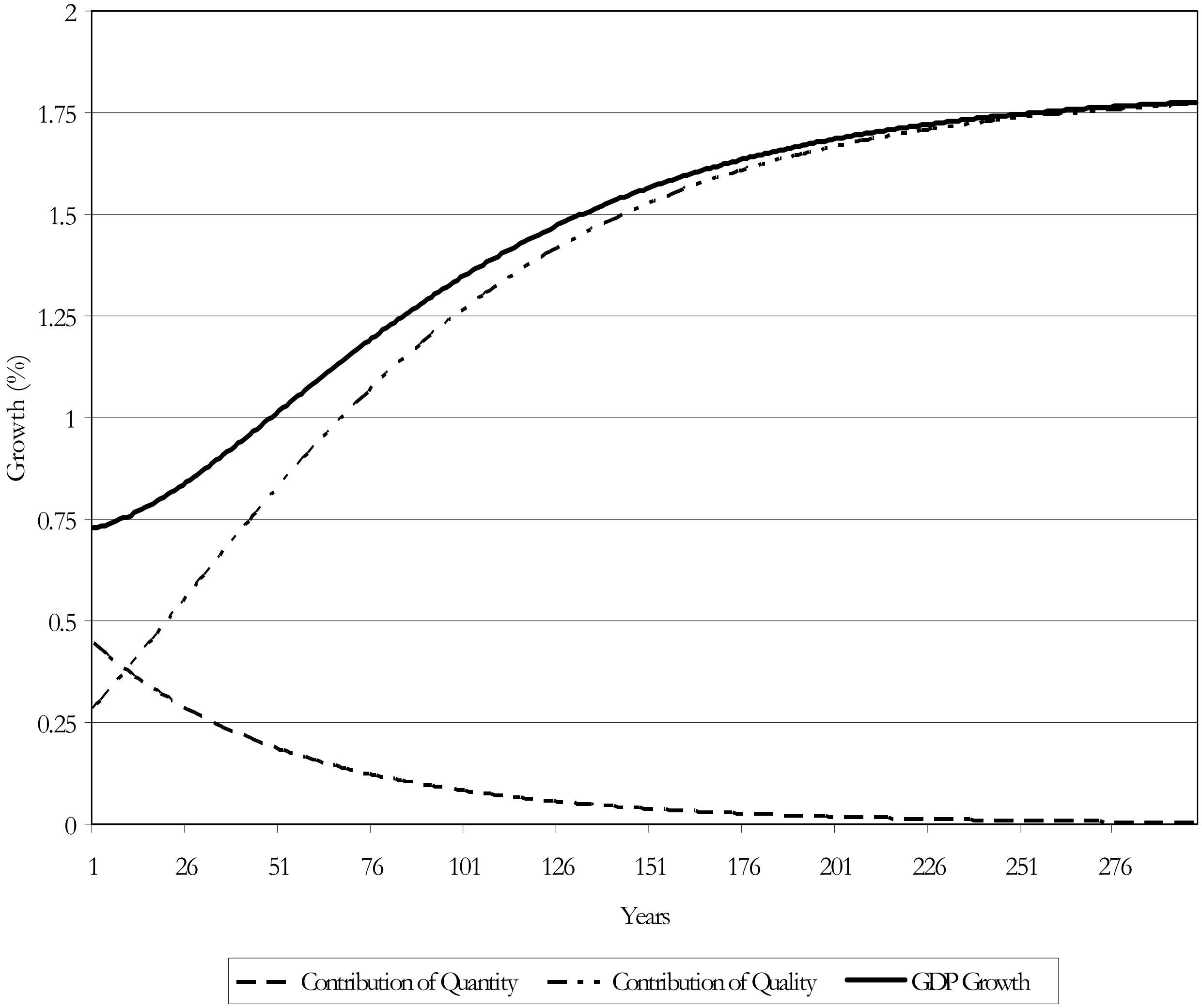
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
Growth (%)
1
26
51
76
101
126
151
176
201
226
251
276
Years
Contribution of Quantity
Contribution of Quality
GDP Growth

Figure 4