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Knowledge, Specialization, Consumption Variety and Trade Dependence

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Abstract

This paper provides an analysis of how the development in knowledge results in expanding the consumption variety via promoting specialization and trade dependence. Gains from specialization and trade are reaped with increasing costs for transacting and with increasing interdependence among agents. As such, consumption variety, specialization, transaction costs (in both absolute magnitude and percentage of the total output of the economy), and trade dependence all evolve. Some preliminary empirical evidence consistent with our theory is also presented. (*JEL*: D11, O12)

Keywords: consumption variety; knowledge; specialization and division of labor; transaction costs; trade dependence; CES utility function.

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1. Introduction

Among the most remarkable features of modern economies are complex trading activities. These include transaction costs increasing both in absolute magnitude and as a percentage of GDP; trade dependence increasing; more and more products and services being traded in the market), increased specialization in virtually all occupations (people being preoccupied with increasingly narrow ranges of productive activities) and continuously expanding consumption varieties. This paper aims to develop a simple theory to endogenize the co-evolution of all the above-mentioned by growth in knowledge and/or improvement in transaction efficiency.

Our story runs as follows. There is some fixed human capital investment in each activity (occupation), hence increasing returns to specialization. There exist complementarity economies in consumption and agents prefer diversity in consumption; or, formally, a constant elasticity of substitution (CES) preference is assumed, but the range of consumption products are to be endogenously determined by the production technology, trading condition and individuals' tastes. To be specialized in producing few products implies exploration of economies to specialization on the one hand and necessity of trading for other products (which in turn requires transaction costs to be incurred) on the other. The balance plays a key role in individuals' decisions regarding specialization patterns and levels. As knowledge grows, productivity increases at the cost of increased human capital investment required by each occupation. Improved productivities and increased occupation-specific human capital investments both reinforce increasing returns to specialization. Consequently, increased

knowledge tilts the balance between economies of specialization on the one side and trading costs and complementarity in consumption diversity on the other in favor of the former. As agents are more specialized, productivity would be improved and the demand and supply of traded products would also be improved. In other words, trade dependence co-evolves with specialization. Furthermore, the new established balance would allow for new products to be introduced into production, trade and consumption. Therefore, consumption variety also evolves. Equally remarkable is that as the market and the division of labor co-evolve, the transaction sector in the economic system expands, not only in absolute magnitude but also in percentage of the aggregate output of the whole economy (GDP). We shall discuss the empirical evidence on this below.

To be sure, much work based on the monopolistic competition model has been done in endogenizing product variety largely by the fundamental balance between *scale economies* in producing each product and individuals' taste for diversity in consumption. For an informative survey, see Lancaster (1990). By contrast, the key determinant of consumption variety here, to emphasize, is the tradeoff between *economies of specialization* (rather than scale economies) on the one hand and transaction costs and taste for diversity in consumption on the other. For a detailed analysis of the often overlooked conceptual difference between scale economies and economies of specialization, see Sun and Lio (forthcoming). Moreover, we focus on the profound implication of growth in knowledge for consumption variety and trade dependence, which manifests itself through promoting individuals' specialization. As such, our analysis draws upon the literature of endogenous specialization, especially focusing

on the effects of growth in knowledge on the division of labor and specialization in general (Becker and Murphy 1992, Sun 2002) and on the effect of utilization of human capital on individual specialization in particular (e.g., Rosen 1983, Barzel and Yu 1984).[1] In addition, this paper provides an analysis integrating the endonegization of consumption variety, trade dependence and increasing transaction costs.

2. **Analysis**

2.1 The setting: a symmetric continuous model

Consider a Walrasian economy with many intrinsically identical agents, who as price takers may however choose *different* occupations and therefore provide different commodities in the market. Each agent is both a consumer and a producer. The preference of each agent is described by a CES utility function,

$$u(.) = \{\int_0^Z x_s^{\rho} ds\}^{1/\rho} \qquad (1)$$

where $\rho < 1$, and x_s is the density of the commodity indexed by s. Z is the range of consumption, as shown below, to be made endogenous. Each agent is endowed with some labor, normalized as one unit, which can be used to produce some commodities described by a range of indices. Note the product index s also serves as the index of activities producing different commodities. In order to acquire the activity-specific skill the agent needs to invest some "training" time, which, even casual observations would suggest, in most cases increases with the available general knowledge. The necessary training time for acquiring the activity-

[1] More detailed reference to the literature will be made later on when drawing insights from modeling

specific human capital is for simplicity assumed to be the same across all commodities, $C_s(H) = C(H)$, $s \in (0, Z)$ where H is the amount of general knowledge, $C' \geq 0$. On the other hand, the productivity is augmented by the general knowledge, $q_s = q(H)$, $s \in (0, Z)$, $q' > 0$.[2] Thus, for L_s hours allocated to producing commodity s, the "training" time is $C(H)$, and the "working" time $L_s - C(H)$. We write the production function as

$$F_H(L_s) = q(H) f(L_s - C(H)), q' > 0, \ f' > 0, f'' < 0, \text{ and } \partial F(L_s)/\partial H > 0 \text{ when } L_s > C(H) \quad (2)$$

$f'' < 0$ is assumed in that the increasing returns to specialization is bounded from above. Causal observations suggest fatigue resulting from engaging in one single activity for long will eventually slow down the productivity.

It is true that one should be specialized in an as narrow range of activities as possible to fully exploit economies to specialization due to the fixed training investment. But to be specialized in few activities necessarily means trading what one produces by herself for other goods/services she does not self-provide and thereby transaction costs necessarily incurred. The tradeoff in most cases would not result in specialization to its fullest. For the sake of exposition, transaction costs are assumed to be borne by buyers alone throughout the paper to simplify the technical analysis. Note this assumption is not much far away from the reality since each buyer (of one good of service) is also a seller (of another) in our model due to her budget balance. Some fixed element of investment, say "set-up" investment (including transport, information, negotiation costs among other things) for establishing the trade link

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analysis.

[2] The double effects of growth in knowledge on the production are articulated in Rosen (1983).

for purchasing each particular commodity, is assumed the same across all commodities (and all agents), denoted as $k, k > 0$. That is, when purchasing y_s units of commodity s from the market, the amount the agent actually obtains is

$$g(y_s) = Max\{0, y_s - k\} \tag{3}$$

The less the value of k, the more efficient the transaction is. k is largely treated as exogenous.[3]

All the products are traded in the market. That is, the possibility of self-sufficiency is purposely ignored for the sake of technical convenience in order to highlight the co-movement of progressive specialization and the expanding consumption variety as knowledge grows. For any given price signal, p_s, $s \in (0, Z)$, the agent optimizes upon her time allocation between training and production, trade plan and consumption variety, subject to the time endowment.

2.2 Time allocation and specialization configurations in equilibrium

As indicated earlier, the agent has an incentive to be engaged in a narrow range of activities to exploit the increasing returns to utilization rate of activity-specific human capital investment, but the transaction costs incurred when trading in the market for other consumption products are correspondingly high. In addition, economies of complementarity in consumption serve as another force against specialization since, should the trading range

be the same, one has to be specialized in producing a narrow range of products at the forgone larger range in consumption. The balance between increasing returns to specialization on the one side, and transaction costs and economies of complementarities in consumption on the other results in the optimal production–trade plan, time allocation and consumption variety. The individual's decision entails both the choice of quantities of any chosen products (the intensive margin) and the choice of variety (the extensive margin) intermediated by the price mechanism.

For each individual, any consumption product is either purchased from the market or produced by herself. It can be shown that for any product indexed by s, $s \in (0, Z)$, the consumer-producer doesn't need to simultaneously produce and purchase the product at optimum in order to save on transaction costs. All the products one consumes are therefore categorized into two groups, (1) products she produces (and trades in the market for other products), of which the product index set is for notational simplicity designated as $[0, L]$; and (2) products she doesn't produce but instead purchases from markets, designated as $[L, L+L'] \equiv [L, Z]$, where $Z \equiv L + L'$ is the consumption variety, to be endogenous below. The decision problem thus turns out to be

$$u(.) = \{\int_0^L \{q(H) f(l_\tau - C(H)) - x_\tau\}^\rho d\tau + \int_L^{L+L'} [g(y_\sigma)]^\rho d\sigma\}^{1/\rho}$$

[3] Indeed, technological change and development of new knowledge, electronic commerce for instance, may reduce the trading cost; or formally, $\partial k / \partial H \leq 0$. We'll discuss below the effect of reduction in transaction costs arising from development of new knowledge.

subject to the time endowment constraint $\int_0^L l_\tau d\tau + \int_L^{L+L'} l_\sigma d\sigma \le 1$ and the budge balance constraint $\int_0^L p_\tau x_\tau d\tau \ge \int_L^{L+L'} p_\sigma y_\sigma d\sigma$ as well as $l_\tau, l_\sigma, x_\tau, x_\sigma \ge 0$, $\forall \tau$ and σ. Here x_τ (y_σ) stands for the amount sold (purchased) of the product indexed by τ (σ), $\tau \in [0, L]$ $(\sigma \in (L, Z])$. Note the symmetry of the model engenders considerable simplification of the decision problem. Furthermore, the utilities of agents who may choose producing different products (or, choose different occupations) are equal with one another due to the intrinsic identity among agents, and therefore the relative price between any pair of products must be unity. In other words, although the intrinsically identical agents would have *ex post comparative advantages* since they choose different occupations in the division of labor, the utilities of all the agents regardless of their occupations should nonetheless be the same. The analysis of the endogenous prices, equaling to unity in our symmetric model, therefore turns out to be a rather trivial exercise. The optimal scope of production, denoted as L*, is determined (refer to Mathematical Appendix for algebraic details), $L^* = l(H, k, C(H))$ where the function $l(H, k, C(H))$ satisfies $l_1 < 0$, $l_2 \equiv \partial L^* / \partial k > 0$, $l_3 \equiv \partial L^* / \partial C(H) < 0$. We are led to,

$$dL^* / dH = l_1 + l_2 \cdot (\partial k / \partial H) + l_3 \cdot (\partial C / \partial H) = l_1 + l_3 \cdot (\partial C / \partial H) < 0 \qquad (4)$$

It is worthwhile to emphasize that agents may produce *different* groups of products, despite the fact that the optimal range of productive activities, the value of L*, is the *same* across all the agents due to symmetry of the model. As knowledge grows, it takes increasingly more time of training to acquire the expertise in each profession. As a

consequence, people would have even stronger incentives to utilize the fixed investment elements in order to fully exploit the economies to specialization. That is, they would be specialized in a narrower range of activities than otherwise, as shown in formula (4). The effect of development in knowledge in general on increased specialization has been widely noticed and analyzed. Ziman (1987), for instance, discusses the remarkable change of landscape in the scientific community with each researcher tends toward to be "knowing everything about nothing", while Becker and Murphy (1992, p.145) addresses finer specialization in the medical, engineering and economics professions driven by development in knowledge. Also see Sun (2002) for a further analysis.

2.3 Transaction costs, consumption variety and trade dependence

Increasing specialization and division of labor go with enlarged extent of the market, as argued long before by Young (1928) when elaborating upon Smith's well-known doctrine of the effect of the market on the division of labor. One crucial element in Smith's economics is that the market not only limits but also coordinates the social division of labor (Hayek 1983). But Young goes further emphasizing that the extent of the market depends on the division of labor too, and therefore the extent of the market and the division of labor can only be seen as being inter-dependent. (For a formal treatment of Young's thesis, see Sun and Lio (forthcoming)). In other words, the trade (extent of the market) and production (the division of labor in production) are re-enforcing each other. As specialization is promoted, the thereby

improved productivity engenders more trading activities among agents and further expansion of the market exchange network. Costs of transacting increase as a consequence.

Due to the symmetry of the model, costs each agent incurs for conducting market exchanges may well serve as a proxy for the total transaction cost of the whole economy, denoted as T, which is equal to (refer to Eq. (A.1) and (A.2) in Appendix),

$$T = L'k = (1-\rho)q(H)Lf(1/L - C(H)) - Lk\rho \tag{5}$$

Noting $\frac{\partial T}{\partial L} = (1-\rho)(qf - qf'/L) - k\rho = -k$ follows from Eq. (A.3). Thus,

$$\frac{dT}{dH} = \frac{\partial T}{\partial L}\cdot\frac{\partial L}{\partial H} + \frac{\partial T}{\partial H} = (-k)\frac{\partial L^*}{\partial H} + (1-\rho)L\cdot\frac{\partial}{\partial H}[q(H)f(1/L - C(H))] > 0 \tag{6}$$

due to $\frac{\partial L^*}{\partial H} < 0$ (Eq. (A.5)), i.e., costs of transacting increases as a consequence of enlarged market extent caused by increase in knowledge. Moreover, the percentage of costs for conducting market exchanges among GDP, denoted as T_ρ,

$$T_\rho = \frac{L'k}{Lq(H)f(\frac{1}{L} - C(H))} = (1-\rho)[1 - \frac{k\rho/(1-\rho)}{q(H)f(\frac{1}{L} - C(H))}] \tag{7}$$

also increases with knowledge H. As analyzed earlier, growth in knowledge surely promotes specialization and the division of labor and thereby brings about both higher productivity for the economy as a whole and more market exchanges. [4]

It is interesting to notice that on the one hand Becker and Murphy (1992) point to the increasing specialization pf physicians in America from the nineteenth century to 1980s as an

example of how knowledge growth drives the division of labor over the said period of time, and one the other Wallis and North (1986) document in details the tremendous growth of costs of transacting both in absolute magnitude and in percentage of GDP (remarkably increasing from roughly one-quarter of GDP in 1870 to over one-half of GDP in 1970 for the American economy). The styled facts documented in Wallis and North's (1986) comprehensive analysis of historical data is well consistent with our theory which predicts the necessary concurrence of growth in knowledge and growth of transaction sector in the economy. Note Becker and Murphy (1992) focuses on knowledge and coordination costs (largely in coordinating team work) rather than costs of market transacting as crucial determinants of the division of labor (as well as "the extent of the market").

It may be also worthwhile to point out that if the transaction efficiency is improved due to technological progress in communication (emergence of telephone, internet for instance), transport (highway, other infrastructure etc.) and/or market-oriented institutional change, the total transaction costs and its share in GDP would both increase despite that the cost of conducting per transaction is less. In fact, from Eq. (5) and (A.4) in Appendix and noting that improvement in transaction efficiency means a smaller value of parameter k,

$$\frac{dT}{dk} = \frac{\partial T}{\partial L} \cdot \frac{\partial L}{\partial k} + \frac{\partial T}{\partial k} = (-k)\frac{\partial L^*}{\partial k} - \rho L < 0 \qquad (8)$$

[4] Note "the growth of the transaction sector is a necessary part of realizing the gains from trade" (Wallis and North 1986, p. 122). We shall address below in more details the issue of increasing costs for market transacting.

due to $\frac{\partial L^*}{\partial k} > 0$ (Eq. A.4). From Eq. (7), the share of transaction costs in GDP is also increasing

$$\frac{dT_\rho}{dk} < 0 \tag{9}$$

The idea that gains from specialization and trade increase with trading conditions in economies, of course, dates back to Adam Smith, and has been investigated systematically by the broadly defined Neo-Institutionalists in recent decades (see, e.g., North 1987, Williamson 1975 and Yang and Ng 1993). In particular, the fact that *reduction* in exchange cost per transaction may result in increase in total transacting costs due to more than proportionate *increase* in trade volume via market exchange was highlighted by North (1987. p. 421).

Another important effect of growth in knowledge is upon the variety of consumption. In choosing the variety of consumption, agents balance the gains from specialization and trade against both the forgone diversity of self-provided products (and thus related costs of transacting incurred when purchasing other products from the market) and complementarity of consumption from a large range of products. Increased knowledge will shift the balance, resulting in higher specialization and hence a larger range of consumption products that could be obtained from market exchange. The expansion of purchased product range outweighs the shrink in self-provided product set due to the promoted specialization, resulting in an enlarged variety of consumption.[5] By Eq. (A.1) and (A.2), the consumption variety,

[5] We focus in this paper on the "demand" side of the new products, undermining in no sense the importance of the issue of how the new products are brought about. Note in the endogenous growth literature, new

$$Z \equiv L + L' = (1-\rho)L^*[\frac{q(H)f(1/L^* - C(H))}{k} + 1] \tag{10}$$

from which follows, $\frac{dZ}{dH} = \frac{\partial Z}{\partial L} \cdot \frac{\partial L}{\partial H} + \frac{\partial Z}{\partial H}$. But note $\frac{\partial Z}{\partial L} = 0$ by Eq. (A.3). Thus

$$\frac{dZ}{dH} = \frac{\partial Z}{\partial H} = \frac{(1-\rho)L}{k} \cdot \frac{\partial (qf)}{\partial H} > 0 \tag{11}$$

A salient feature of advanced economies compared to less advanced ones is that consumers in the former enjoy a more differentiated, diverse consumption product set than in the latter. Moreover, the expansion of available consumption range in advanced economies has exhibited itself over time, largely driven by technology progress, or growth in knowledge. Linder (1961) has long before noticed both the theoretical causality from high productivity to product variety and the related empirical evidence. Gronau and Hamermesh's (2001) recent study demonstrates significant positive correlation between education and demand for consumption variety using survey data generated from six developed countries during 1985-1994.

As regards the effect of trading efficiency on consumption diversity, one can show from (10) that

$$\frac{dZ}{dk} = \frac{\partial Z}{\partial L} \cdot \frac{\partial L}{\partial k} + \frac{\partial Z}{\partial k} = \frac{\partial Z}{\partial k} = \frac{-(1-\rho)Lqf}{k^2} < 0 \tag{12}$$

Should other things be the same, if the trading condition is improved, there will be incentives for the agent to be more specialized in a narrow range of productive activities since the

products are introduced as one part of innovation resulting from R&D investment (see, e.g., Grossman and

trading costs for each transaction would be correspondingly reduced and hence the market size for each individual enlarged. That is, more market exchanges will be carried out and the promoted specialization will lead to an enlarged range of consumption. The social division of labor is thereby enhanced. Many factors, for instance, transportation networks, well-established routines in doing business, legal system etc., produce profound influence on the transaction efficiency. Yang and Shi (1992) developed a nice *discrete* product model to investigate how the improved transaction condition may drive up specialization and consumption variety. But knowledge and human capital are both absent in their analysis. The *continuous* product model presented in this paper incorporates the human capital element (Rosen 1983, Barzel and Yu 1984) and knowledge (Becker and Murphy 1992, Sun 2002) as crucial determinants of labor specialization to further address how the evolution of product variety is brought about by growth in knowledge. Note the "transaction (costs)" may be literally interpreted as including coordination (costs), for in a large network of the division of labor with many differentiated specialists one has to communicate and coordinate with others by trading ideas and information.[6]

Perhaps not surprisingly, increase in trade dependence, defined as the ratio of trade volume to aggregate output, denoted as r, $r = \frac{\alpha}{qf} = 1 - \frac{k\rho}{(1-\rho)qf}$, concurs with promotion in specialization and evolution in product variety, as a consequence of growth in knowledge

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Helpman 1991). We'll come back to this point below.

[6] It is true that increased knowledge and technological change do have influence on the trading/ coordination efficiency, parameter k in our model, and that it is easy to show that the positive effect of knowledge on the division of labor would be even greater provided that $\partial k / \partial H < 0$, which seems to hold in most cases.

(and/or reduction in trade barriers). $\frac{dr}{dH} = \frac{\partial r}{\partial L} \cdot \frac{\partial L}{\partial H} + \frac{\partial r}{\partial H} > 0$ since $\frac{\partial r}{\partial L} < 0$, $\frac{\partial L}{\partial H} < 0$ and $\frac{\partial r}{\partial H} > 0$. In other words, trade growth more than proportionately as productivity increases due to technical progress (knowledge growth), or improved trading condition. Note Barker's (1977) variety hypothesis, which is developed for addressing growth in international trade related to productivity growth, holds a similar argument that agents are enabled to purchase more than proportionately as productivity improves and thereby the trade dependence and integration of markets are promoted.

3. Concluding remarks

We submit in this paper that growth in knowledge results in an increase in both productivity of each working hour and activity-specific human capital investment, and therefore the effect of utilization rate of human capital on the increasing returns to specialization is reinforced. The balance between the economies of specialization on the one hand and the costs of transacting and consumption diversity in preference on the other is tilted toward the former as a consequence of growth in knowledge (or reduction in cost for conducting each market exchange). Evolution in specialization, consumption variety and trade dependence concur.

Our focus on the profound effect of knowledge on productivity and trade should in no sense be interpreted as suggesting that the implication of improvement in trading efficiency is unimportant. The effect is of course great. Besides that, it is worthwhile to mention that trading efficiency is often significantly effected positively by increase in knowledge (internet

and the induced e-commerce come to mind). If the trading technology parameter in our model is allowed to be contingent upon knowledge, the effect of growth in knowledge on specialization, product variety and trade dependence would only be even stronger. On the other hand, further promoted specialization induced by increased knowledge sometimes renders it harder for people of different occupations to hold common belief and common knowledge, and hence making it harder to communicate and trade (goods, services, ideas etc) with one another (cf. North 1987, Ziman 1987). Thus, the *indirect negative* effect of knowledge growth on trading efficiency could also be another element complicating the analysis. More work needs to done along these lines.

Knowledge growth is treated as exogenous in our analysis. A more realistic treatment is to make it endogenized. Becker and Murphy (1992, Section VI) developed an aggregate model wherein an inter-temporal consumption allocation problem is solved with saving (investment) made in one period being used to (automatically) generate new knowledge that is used as inputs in production in the next period. They also formally analyze the economy consisting of two sectors with one producing final products and the other producing human capital (education) to further explore into how the generation of new knowledge could be incorporated into analysis. But one crucial point at issue revealed from Loasby's (1996) scrutiny of Adam Smith is that new knowledge not only result *in* but also results *from* further division of labor. The mutual reinforcement between knowledge and division of labor is necessarily a dynamic interplay story, which has far yet to be analyzed in the literature.

We purposely simplify the production function in this paper, assuming away joint production and capital products. To be sure, increasing diversity in capital goods is a no less remarkable phenomenon than that in consumption products in advanced economies. Should human capital be incorporated into Sun and Lio's (forthcoming) industrialization model that centers around the co-evolution of the division of labor and variety of capital goods driven by improved trading efficiency, a story of evolution in capital product variety caused by knowledge growth may be well told. Another possible extension from this analysis is to incorporate team production and the related coordination problem to further develop a theory of interplay among growth, coordination and evolving division of labor.

Mathematical Appendix

As analyzed in the text, the formulation of the individual's production-trade-consumption decision problem can be much simplified due to the symmetry of the model. The symmetry requires the time to be allocated evenly among all the productive activities and the amount sold of each product the same. Further noting that at market equilibrium the relative price of any pair of traded products is unity, the individual problem thus becomes, Max $u(.) =$

$$\{\int_0^L [q(H)f(\frac{1}{L}-C(H))-x]^\rho ds \quad + \int_L^{L+L'} (\frac{Lx}{L'}-k)^\rho ds\}^{1/\rho} = \quad \{L[q(H)f(\frac{1}{L}-C(H))-x]^\rho \quad + L'(\frac{Lx}{L'}-k)^\rho\}^{1/\rho}$$

subject to the nonnegative-ness constraints of the decision variables, L (the range of production activities), x (the amount sold of each product produced) and L' (the range of purchased products). The budge balance condition has been taken into account in the last term of the above formula. Note the consumption variety $Z \equiv L + L'$ is thus an endogenous variable. We proceed in two steps to solve the above utility maximization problem. For any given range of activities L, the first order conditions with respect to x and L' yield (the second order condition is easy to verify),

$$L' = ((1-\rho)Lx)/k \qquad \text{(A.1)}$$

and

$$q(H)(f(1/L - C(H)) - x = k\rho/(1-\rho) \qquad \text{(A.2)}$$

from which follows $u(.) = k\rho(1-\rho)^{(1-\rho)/\rho}\ [L + q(H)Lf(\frac{1}{L}-C(H))/k]^{1/\rho}$. Differentiating $u(.)$ with respect to L leads to

$$V(H,k,L) \equiv q(H)[\frac{1}{L} \cdot f'(\frac{1}{L} - C(H)) - f(\frac{1}{L} - C(H))] - k = 0 \qquad \text{(A.3)}$$

by which the optimal range of production that the agent is engaged in, denoted as L*, is implicitly determined as a function of H and k. It follows that $\partial V / \partial k < 0$, $\partial V / \partial L = -q(H) f'' / L^3 > 0$ and $\partial V / \partial H|_{L^*} = kq' / q + q[-C' f'' / L + f' C'] > 0$. Therefore,

$$\partial L^* / \partial k > 0 \qquad \text{(A.4)}$$

and

$$\partial L^* / \partial H < 0 \qquad \text{(A.5)}$$

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