Structural Change, Urban Congestion, and the End of Growth*

Volker Grossmann†

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Abstract

This paper develops a two-sector R&D-based growth model with congestion effects from increasing urban population density. We show that endogenous technological progress causes structural change if there are positive productivity spillovers from the modern to the traditional sector and Engel's law holds. In turn, urban congestion effects cause a productivity slowdown in the modern sector. Eventually, economic growth may cease in the long-run. We also show that land dilution by a larger workforce may give rise to negative scale effects on GDP per capita.

Key words: Congestion; Endogenous growth; Engel's law; Structural change; Urbanization.

JEL classification: O10, O30, O40.

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† University of Fribourg, Switzerland; CESifo, Munich; Institute for the Study of Labor (IZA), Bonn. *Address:* Department of Economics, University of Fribourg, Bd. de Pérolles 90, CH-1700 Fribourg, Switzerland. *Phone:* +41-26-3009383. *E-mail:* volker.grossmann@unifr.ch.

1 Introduction

According to United Nations projections, more than three-fifths of the world's population will live in urban areas by 2025. Urbanization gives rise to congestion effects like traffic jams, traffic accidents, crowded public transport, overcharged electricity networks, pollution, noise, crime, and communicable diseases.[1] Urbanization is particularly rapid in fast-growing China and India, which causes huge problems in cities like Beijing, Shanghai, Dehli and Mumbai. For instance, exploding motorization is responsible for a surge in both traffic fatalities and air pollution. Average roadway speeds for motor vehicles substantially declined to often less than 10 km/h in central areas (Pucher et al., 2007).

Henderson (2003) provides empirical evidence that urbanization is a by-product rather than the cause of economic growth. He finds that there is an optimal degree of urbanization which maximizes productivity growth and too high an urban concentration can be very costly. A question which immediately arises from potentially severe urban congestion effects is whether productivity growth can be sustained in the long-run. Surprisingly, this question is largely under-researched in the literature on economic growth.

This paper develops a two-sector R&D-based growth model in which rising urban population density, associated with endogenous structural change, has adverse productivity effects. Structural change results from three basic features of the model: first, there is endogenous technological progress in the modern ("industrial") sector, characterized by imperfect competition and increasing returns. Second, productivity advances in the modern sector spill over to the traditional ("agricultural") sector (e.g. Greenwald and Stiglitz, 2006). Third, and consistent with a large body of empirical evidence (surveyed by Browning, 2008), the income elasticity of demand for the agricultural good is less than unity ("Engel's law"). The property is implied by the assumption that there is a subsistence level of consumption of the agricultural good.

We show that positive productivity spillovers from the modern to the traditional sector cause a reallocation of labor towards the modern sector when Engel's law holds. In

[1] The WHO event World Health Day 2010 about 'Urbanization: a challenge for public health' stressed that communicable diseases like viral hepatitis, HIV/AIDS and tuberculosis are concentrated in urban areas. Moreover, cities are at particular risk of pandemic infectious diseases.

turn, such structural change leads to congestion in the urban area and therefore to a productivity slowdown in the modern sector. Under certain conditions, economic growth may cease in the long-run. The analysis thus identifies conditions under which productivity growth leads to structural change. If these conditions are met, congestion effects suggest a pessimistic outlook for the future of economic growth. This is not to deny that there may be mechanisms which could mitigate such outcome. Agglomeration effects in the sense that an increasing city population enhances individual knowledge would be an example (e.g. Lucas, 2009), from which we abstract to focus the analysis.

We also address the long-standing debate in the endogenous growth literature on scale effects and show that these may not be positive. Positive scale effects are said to occur if an increase in the labor force either causes the growth rate or the level of per capita income to rise. The proposed framework belongs to the class of second-generation endogenous growth models with vertical innovations where strong scale effects (i.e., with respect to the growth rate) are removed.[2] Intermediate good firms can freely enter and the average quality of producer goods matters for growth-generating intertemporal R&D spillovers (Young, 1998). In standard versions of such a model, specialization gains from an increased number of firms (associated with higher population size) still cause scale effects in levels. However, at least in modern times, the evidence of any kind of positive scale effect seems to be, at best, mixed, even when accounting for international trade relations (e.g. Frankel and Romer, 1999; Rodrik, Subramanian and Trebbi, 2004).[3] That scale effects are not necessarily positive in the model proposed in this paper naturally follows from the basic premise that land is a critical factor also for modern production. Examples include access to railways, airports, rivers and roads at the location of plants as well as office space in cities. As land is a fixed factor, a larger labor force causes land dilution effects which may dominate specialization gains. Consequently, per capita income may decline, i.e., scale effects may be negative. One contribution of this paper

[2] See Jones (1999, 2005) for discussions of the scale effect problem in endogenous growth theory. Bretschger and Smulders (2012) suggest a new way of removing strong scale effects in a multi-sector endogenous growth model with resource depletion, when sectors differ in substitutability between labor and natural resources.

[3] See Grossmann (2009) for a discussion of empirical evidence. In his theoretical framwork, innovating entrepreneurs operate in perfect competition such that scale effects from specialization gains cannot arise in his framework.

is to conceptually separate land dilution effects from congestion effects and to show that the latter are not necessary to remove scale effects.

There is a large literature on structural change, surveyed by Matsuyama (2008), which stresses both demand and supply factors. Our two-sector framework with non-homothetic preferences and endogenous growth may be most closely related to Matsuyama (1992). He stresses that an increase in agricultural productivity may squeeze out the manufacturing sector and therefore prevent learning-by-doing effects in an open economy. In a closed economy, by contrast, the opposite holds in his framework due to a reallocation of labor towards manufacturing. There are three key differences of our model to Matsuyama (1992). First, productivity gains in the industrial sector are driven by R&D rather than learning-by-doing effects. Second, agricultural productivity growth is linked to innovative activity in the modern sector rather than being exogenous. Third, we model urban congestion effects. Consequently, even in a closed economy an increase in agricultural productivity may be harmful for growth.

A more recent literature deals with models of non-balanced economic growth, which are, under certain conditions, consistent with the Kaldor facts in the aggregate. For instance, Kongsamut, Rebelo and Xie (2001), Föllmi and Zweimüller (2006) and Boppart (2011) develop growth models in which the income elasticity of demand differs across sectors. Acemoglu and Guerrieri (2008) allow for different capital intensities across sectors. Ngai and Pissarides (2007) propose a model with different growth rates across sectors. The focus of these contributions on the Kaldor facts is rather different to our focus on growth slowdowns caused by urban congestion effects.

With respect to the scale effects prediction, this paper is not the first one which suggests how positive scale effects on per capita income can be removed. Dalgaard and Kreiner (2001) and Strulik (2005, 2007) employ infinite-horizon growth models with ever increasing average human capital levels. They argue that faster population growth depresses the level of human capital per worker, similar to an increase in the depreciation rate of human capital. Their line of reasoning is thus different to the land dilution effects stressed here. Acemoglu and Johnson (2007) argue that higher life expectancy may lower per capita income in a Solow-type neoclassical growth model by lowering the land-labor ratio.[4] One contribution of the present paper is to show that a similar type of argument can remove even weak scale effects (i.e., with respect to levels) in endogenous growth models with imperfect competition and specialization gains.

Finally, there are two different strands of the literature on the role of congestion effects for long-run growth. The first one focusses on the role of public infrastructure for optimal linear income taxation in one-sector growth models (e.g. Barro and Sala-i-Martin, 1992; Glomm and Ravikumar, 1994, 1997; Turnovsky, 1997; Eicher and Turnovsky, 2000). In contrast, this paper highlights the interaction between productivity growth, urban population density and structural change. This is not to deny that public infrastructure investment can mitigate urban congestion. However, this paper is based on the premise that ultimately land will be the limiting factor, whereas the previous growth literature rests on the hypothesis that public infrastructure capital can limit congestion indefinitely.

The second strand of the literature on congestion and growth comprises interesting recent contributions on the interaction between fertility, demand for natural resources and endogenous technological change. Bretschger (2012) introduces congestion effects from larger population size on the net birth flow. He shows that, given that congestion effects are limited, long run growth can be sustained even though non-renewable, depleted natural resources are essential for both goods production and knowledge accumulation. Peretto and Valente (2011) study the interaction between fertility dynamics and R&D-based growth. They show that, when individuals have a minimum requirement of a natural resource (like land), there will be constant population and exponentional income growth in the long run. In contrast to these contributions, we hypothesize that congestion effects occur at the knowledge accumulation process. Moreover, we relate knowledge dynamics to structural change from traditional to modern production.

The paper is organized as follows. Section 2 presents the model. Section 3 analyzes the equilibrium by distinguishing between congestion and dilution effects. The last section concludes.

[4] Their empirical evidence suggests that the causal effect of higher life expectancy on per capita income is negative, lending some support for land dilution effects investigated in this paper.

2 The Model

Consider the following Ricardo-Viner type two-sector model with one intersectorally mobile factor ("labor") and two immobile, fixed factors ("land"). Factor markets are competitive. Modern ("industrial") production is characterized by increasing returns and may suffer from congestion effects. The focus on non-accumulated immobile factors and congestion in the modern sector permits the interpretation of industrialized production taking place in the urban region, which is of land size $\bar{Z}_M$. By contrast, traditional ("agricultural") production takes place in the rural region, with land size $\bar{Z}_A$. As usual, the notion of traditional production is that there are many small, perfectly competitive firms with a constant-returns to scale technology. Goods can be costlessly transported between regions. Migration of labor across sectors is costless as well. We consider a small open economy with an internationally given interest rate $\bar{r} > 0$. Time $t = 1, 2, ...$ is discrete. The time index is omitted whenever this does not lead to confusion.

2.1 Individuals and Endowments

There are (ex-ante) identical $\bar{L}$ individuals with dynastic preferences who act as infinitely-living. Each period, they inelastically supply one unit of labor in the region they live. Moreover, each individual owns $\bar{Z}_A/\bar{L}$ units of land located in the rural region and $\bar{Z}_M/\bar{L}$ units of land in the urban region.

Each individual decides where to locate and chooses the time path for consumption of a manufacturing good, $c_{M,t}$, and an agricultural good, $c_{A,t}$. Preferences are represented by intertemporal utility function

$$U = \sum_{t=0}^{\infty} \rho^t \log u(c_{M,t}, c_{A,t}), \tag{1}$$

$\rho \in (0, 1)$, where instantaneous utility u is of the Stone-Geary type:

$$u(c_M, c_A) = (c_M)^{\gamma}(c_A - \bar{c})^{1-\gamma}, \tag{2}$$

$\gamma \in (0, 1)$, $\bar{c} \geq 0$. If there exists a positive subsistence level of agricultural consumption,

$\bar{c} > 0$, preferences are non-homothetic. For simplicity, we employ the standard assumption

$$\rho(1 + \bar{r}) = 1. \tag{A1}$$

As will become apparent, assumption (A1) implies that demand for the manufacturing good is constant over time. Denote the rental rates of land for agricultural and manufacturing production by r_A and r_M, respectively. With analogous notation for wage rates, as labor is intersectorally mobile, in equilibrium, $w_A = w_M = w$ must hold. Thus, each individual earns income

$$y = w + \frac{r_A \bar{Z}_A + r_M \bar{Z}_M}{\bar{L}}. \tag{3}$$

Denote by p_A the price of the agricultural good and normalize the price of the manufacturing good to unity, $p_M = 1$. Financial assets of an individual, denoted by a, accumulate according to $a_{t+1} = (1 + \bar{r})a_t + y_t - p_{A,t}c_{A,t} - c_{M,t}$, where $a_0 \geq 0$ is given. Imposing the standard "No-Ponzi game" condition, $\lim_{T\to\infty} \frac{a_{T+1}}{(1+\bar{r})^T} = 0$, the intertemporal budget constraint can be written as

$$\sum_{t=0}^{\infty} \frac{p_{A,t}c_{A,t} + c_{M,t}}{(1 + \bar{r})^t} = (1 + \bar{r})a_0 + \sum_{t=0}^{\infty} \frac{y_t}{(1 + \bar{r})^t} \equiv W. \tag{4}$$

Let λ denote the Lagrange multiplier on constraint (4) when maximizing utility U. Using (A1) and specificiation (2) for instantaneous utility, it is straighforward to show that the demand structure of each individual in t reads

$$c_{M,t} = \frac{\gamma}{\lambda(W, \mathbf{p}_A)} \equiv \tilde{c}_M(\mathbf{p}_A, W), \tag{5}$$

$$c_{A,t} = \frac{1 - \gamma}{\lambda(W, \mathbf{p}_A)p_{A,t}} + \bar{c} \equiv \tilde{c}_A(\mathbf{p}_A, p_{A,t}, W), \tag{6}$$

where $\mathbf{p}_A = \{p_{A,s}\}_{s=0}^{\infty}$ denotes the sequence of prices for the agricultural good and

$$\lambda(W, \mathbf{p}_A) \equiv \frac{1}{(1 - \rho)\left(W - \bar{c}\sum_{s=0}^{\infty} \rho^s p_{A,s}\right)}. \tag{7}$$

According to (5) and (7), if there exists a subsistence consumption level of the agricultural good, $\bar{c} > 0$, the elasticity of manufacturing consumption, c_M, with respect to the present discounted value of individual "life-time wealth" W is above unity. Moreover, in a steady state where p_A is time-invariant, it is easy to show from (6) and (7) that the elasticity of agricultural consumption, c_A, with respect to W is below unity if and only if $\bar{c} > 0$. In this sense, the case of non-homothetic preferences is consistent with Engel's law.

2.2 Technology

The industrial sector produces competitively produces the manufacturing consumption good in the urban region. It combines labor and differentiated intermediate inputs. Formally, output is given by

$$Y_M = (L_M)^{1-\alpha} \int_0^n (A(i))^{1-\alpha} (x(i))^{\alpha} \mathrm{di}, \tag{8}$$

$0 < \alpha < 1$, where L_M denotes labor input in manufacturing, $x(i)$ is the quantity of intermediate input $i \in [0, n]$, and $A(i)$ is a quality measure of i.

Production of an intermediate good requires a fixed number $f > 0$ of workers each period (overhead staff). Fixed costs give rise to increasing returns and imperfect competition. Each intermediate good is produced by one monopolistically competitive firm. The mass ("number") of intermediate good firms, n, is endogenous and determined by free entry. One unit of output of an intermediate good requires one unit of urban land. That is, marginal costs are equal to the rental rate of land in the urban region, r_M.

Denote by $\bar{A} \equiv \frac{1}{n} \int_0^n A(i) \mathrm{di}$ the average quality of intermediate goods, where the initial level $\bar{A}_0 > 0$ is given. $\bar{A}$ may be interpreted as "knowledge stock" in the industrial sector. By employing $l_t(i)$ R&D workers in period t prior to production, intermediate good firm i can offer in period t product quality

$$A_t(i) = \frac{(\bar{A}_{t-1})^{\phi}}{(D_t)^{\theta}} h(l_t(i)), \tag{9}$$

$\phi > 0$, $\theta > 0$, where D is the urban population density, i.e., the number of workers in the urban region, $\tilde{L}_M := L_M + \int_0^n (l(i) + f)\mathrm{di}$, per unit of urban land: $D := \frac{\tilde{L}_M}{Z_M}$. Like other aggregates, D is taken as given by firms. Function h is increasing and strictly concave with $h(0) \geq 0$. To ensure an interior solution for the optimal R&D choice, suppose "Inada conditions" $\lim_{l\to\infty} h'(l) = 0$, $\lim_{l\to 0} h'(l) \to \infty$ hold. As $\phi > 0$, there is a standard "standing on shoulders effect" from access to previous knowledge. Parameter θ is the (constant) elasticity of product quality of an intermediate goods firm with respect to urban population density. Thus, θ measures the strength of urban congestion effects from higher population density.[5]

The agricultural sector is competitive. It produces by combining land and labor according to a constant-returns to scale technology. For simplicity, we focus on the Cobb-Douglas case. Output Y_A is given by

$$Y_A = B(Z_A)^{\beta} (L_A)^{1-\beta}, \tag{10}$$

where L_A is labor input in agriculture and Z_A is land input; $B > 0$.

Following Greenwald and Stiglitz (2006), there may be a cross-sectoral technological spillover effect from the manufacturing sector to the agricultural sector. The spillover takes place with a lag of one period. Formally, the total factor productivity of the traditional sector in period t is given by

$$B_t = b(\bar{A}_{t-1}), \tag{11}$$

$b' \geq 0$. We will examine the implications of the case $b' > 0$ vis-à-vis the case $b' = 0$.

We assume throughout that the subsistence level of agricultural consumption, $\bar{c}$, is smaller than agricultural output per worker in the case where all individuals work in the traditional sector. Formally,

$$\bar{c} < B \cdot \left(\frac{\bar{Z}_A}{\bar{L}}\right)^{\beta}. \tag{A2}$$

[5] One may argue that higher population density, D, can exert positive spillover (e.g. learning) effects among individuals, like in Lucas (2009). Realistically, this requires that D is below some threshold level. In this paper, for simplicity and in order to focus on congestion effects, this threshold level is assumed to be zero.

Assumption (A2) ensures the existence of an interior equilibrium.[6]

3 Equilibrium Analysis

Denote by p_i the price set by intermediate good firm $i \in [0, n]$. The equilibrium is defined as follows.

Definition 1. *An equilibrium is given by a time sequence of prices* $(p_A, r_M, r_A, w_M, w_A, \{p(i)\}_{i\in[0,n]})$*, quantities* $(Y_M, Y_A, L_M, L_A, Z_A, \{l(i), x(i)\}_{i\in[0,n]})$*, quality levels* $\{A(i)\}_{i\in[0,n]}$*, and a firm number* n *such that at all times*

(i) the final manufacturing goods sector, intermediate goods firms, and the agricultural sector maximize profits;

(ii) intermediate goods firms have zero profits (free entry condition);

(iii) the labor markets clears: $\tilde{L}_M + L_A = \bar{L}$*, where* $\tilde{L}_M = L_M + \int_0^n (l(i) + f)\mathrm{di}$*;*

(iv) workers maximize utility; in particular, they are indifferent where to locate: $w_M = w_A = w$*;*

(v) land markets clear in both regions: $\int_0^n x(i)\mathrm{di} = \bar{Z}_M$*,*[7] $Z_A = \bar{Z}_A$*;*

(vi) consumption goods markets clear: $Y_M = \bar{L}\tilde{c}_M(\mathbf{p}_A, W)$*,* $Y_A = \bar{L}\tilde{c}_A(\mathbf{p}_A, p_A, W)$*.*

3.1 Urban Congestion Effects

Lemma 1: *There exists a symmetric and time-invariant equilibrium R&D labor input; i.e.,* $l_t(i) = l^*$ *for all* $i \in [0, n_t]$ *and* $t \geq 1$*.* l^* *is uniquely given by*

$$1 = \frac{h'(l^*)}{h(l^*)}(l^* + f). \tag{12}$$

All proofs are relegated to the appendix. Lemma 1 is an implication of the ex-ante symmetry and free entry of intermediate goods firms. Consequently, all firms offer the

[6] Since for $b' > 0$ productivity level B may change over time, we have to assume that (A2) holds for all t. As will become apparent, this is ensured if (A2) holds for $t = 1$ and $\bar{A}_0 < \bar{A}_1$.

[7] Recall that one unit of output of an intermediate good requires one unit of urban land.

same product quality, $A_t(i) = \bar{A}_t$ for all t. Moreover, R&D labor input per firm is independent of endowments; that is, it does neither depend on population size ($\bar{L}$) nor on land supply ($\bar{Z}$). The equilibrium number of intermediate goods firms increases proportionally to $\bar{L}$ (see appendix), leaving l^* unaffected (e.g. Young, 1998).

Define the fraction of labor in the traditional sector by $l_A := \frac{L_A}{\bar{L}}$ and denote its equilibrium level by l_A^*. The following holds.

Lemma 2: *In equilibrium, there exists a unique value for the fraction of labor in agriculture, $l_A^*(B, \bar{L})$, which is implicitly given by*

$$l_A^* = \frac{1 + \frac{\chi \bar{c}}{B} \left(\frac{l_A^* \bar{L}}{\bar{Z}_A} \right)^{\beta}}{1 + \chi}, \tag{13}$$

where $\chi \equiv \frac{\gamma(1-\alpha^2)}{(1-\beta)(1-\gamma)} > 0$. If $\bar{c} > 0$, $l_A^*(B, \bar{L})$ is decreasing in agricultural productivity (B) and increasing in population size ($\bar{L}$). For $\bar{c} = 0$, $l_A^* = \frac{1}{1+\chi}$ is independent of both B and $\bar{L}$.

Comparative-static results in Lemma 2 can be understood as follows. First, for a given relative goods price, p_A, an increase in agricultural productivity, B, or in rural land input per agricultural worker, $\frac{\bar{Z}_A}{L_A}$, raises the marginal productivity of labor in the agricultural sector, w_A. Second, since output of the agricultural good increases, there is a negative effect on relative price p_A, in turn leading to a decrease in w_A. If and only if Engel's law holds ($\bar{c} > 0$), then the second effect dominates the first one. Thus, if $\bar{c} > 0$, the incentive to work in the traditional sector is weakened when B increases and strengthened if $\bar{L}$ increases.

Recall that, if $b' > 0$, a higher past industrial knowledge stock, $\bar{A}_{t-1}$, raises current agricultural productivity, B_t. Thus, the following result is implied by Lemma 2.

Proposition 1: (Structural change) *If $b' > 0$ and $\bar{c} > 0$, an increase in the average intermediate good quality, $\bar{A}_{t-1}$, induces structural change, i.e., $\tilde{l}_A^*(\bar{A}_{t-1}, \bar{L}) := l_A^*(b(\bar{A}_{t-1}), \bar{L})$ declines. Otherwise (if $b' = 0$ or $\bar{c} = 0$), an increase in $\bar{A}_{t-1}$ has no effect on the equilibrium allocation of labor.*

Proposition 1 suggests that R&D-related productivity progress in the manufacturing sector induces structural change and thus migration of labor into the urban area if and only if two conditions simultaneously hold: there is a subsistence level of consumption of the traditional good ($\bar{c} > 0$) and there are cross-sectoral productivity spillovers ($b' > 0$).

According to equilibrium condition (iii) in Definition 1, we have $\tilde{L}_M = (1 - l_A)\bar{L}$. Recalling $D = \frac{\tilde{L}_M}{\bar{Z}_M}$ and using $l_A = \tilde{l}_A^*(\bar{A}_{t-1}, \bar{L})$, equilibrium urban population density in period t can therefore be written as

$$D_t = \frac{\left[1 - \tilde{l}_A^*(\bar{A}_{t-1}, \bar{L})\right] \bar{L}}{\bar{Z}_M} \equiv D^*(\bar{A}_{t-1}, \bar{L}). \tag{14}$$

Corollary 1: *If $\bar{c} > 0$ and $b' > 0$, D_t is increasing in $\bar{A}_{t-1}$; otherwise, D_t is independent of $\bar{A}_{t-1}$.*

Using Lemma 1 and (14) in (9), in equilibrium, the industrial knowledge stock evolves according to the first-order difference equation

$$\bar{A}_t = \frac{(\bar{A}_{t-1})^\phi h(l^*)}{D^*(\bar{A}_{t-1}, \bar{L})^\theta} \equiv \Omega(\bar{A}_{t-1}; \bar{L}). \tag{15}$$

It is evident that, in the proposed simple model, dynamics are entirely driven by the knowledge stock $\bar{A}$. It thus suffices to focus on (15).

Consider the elasticity

$$\varepsilon := \frac{\partial \bar{A}_t}{\partial \bar{A}_{t-1}} \frac{\bar{A}_{t-1}}{\bar{A}_t} = \phi - \theta \frac{\bar{A}_{t-1}}{D_t} \frac{\partial D_t}{\partial \bar{A}_{t-1}} \tag{16}$$

Like in standard endogenous growth models without potential congestion ($\theta = 0$), there is positive endogenous growth even in the long-run under the standard assumption of a linear intertemporal knowledge spillover effect ($\phi = 1$), if technical progess does not affect urban population density, $\frac{\partial D_t}{\partial \bar{A}_{t-1}} = 0$. In this case, $\varepsilon = 1$ and $\bar{A}_t$ is proportional to $\bar{A}_{t-1}$. Consequently, the economy immediately jumps onto a balanced growth path.[8] By contrast, consider the case where there is a reallocation of labor towards manufacturing

[8] According to (15), the growth rate is positive when $h(l^*) > (D^*)^\theta$.

as productivity advances, i.e. $\frac{\partial D_t}{\partial \bar{A}_{t-1}} > 0$. According to Corollary 1, this happens if and only if at the same time there are cross-sectoral spillovers ($b' > 0$) and Engel's law holds ($\bar{c} > 0$). In this case, we have $\varepsilon < 1$ even when the intertemporal spillover is linear ($\phi = 1$). Consequently, economic growth cannot be sustained in the long-run. We shall thus focus on the case $\phi = 1$ when stating the following key result of the paper.[9]

Proposition 2: (Evolution of the industrial knowledge stock) *Suppose that the intertemporal spillover is linear, $\phi = 1$.*

(a) If $b' > 0$ and $\bar{c} > 0$, then economic growth ceases in the long-run. In this case, adjustment to the steady state level of industrial knowledge stock, which is given by $\bar{A}^* = \Omega(\bar{A}^*; \bar{L})$, may be gradual or cyclical. It is also possible that $\bar{A}^*$ is unstable.

(b) If $b' = 0$ or $\bar{c} = 0$, there are no transitional dynamics and economic growth can be sustained in the long run.

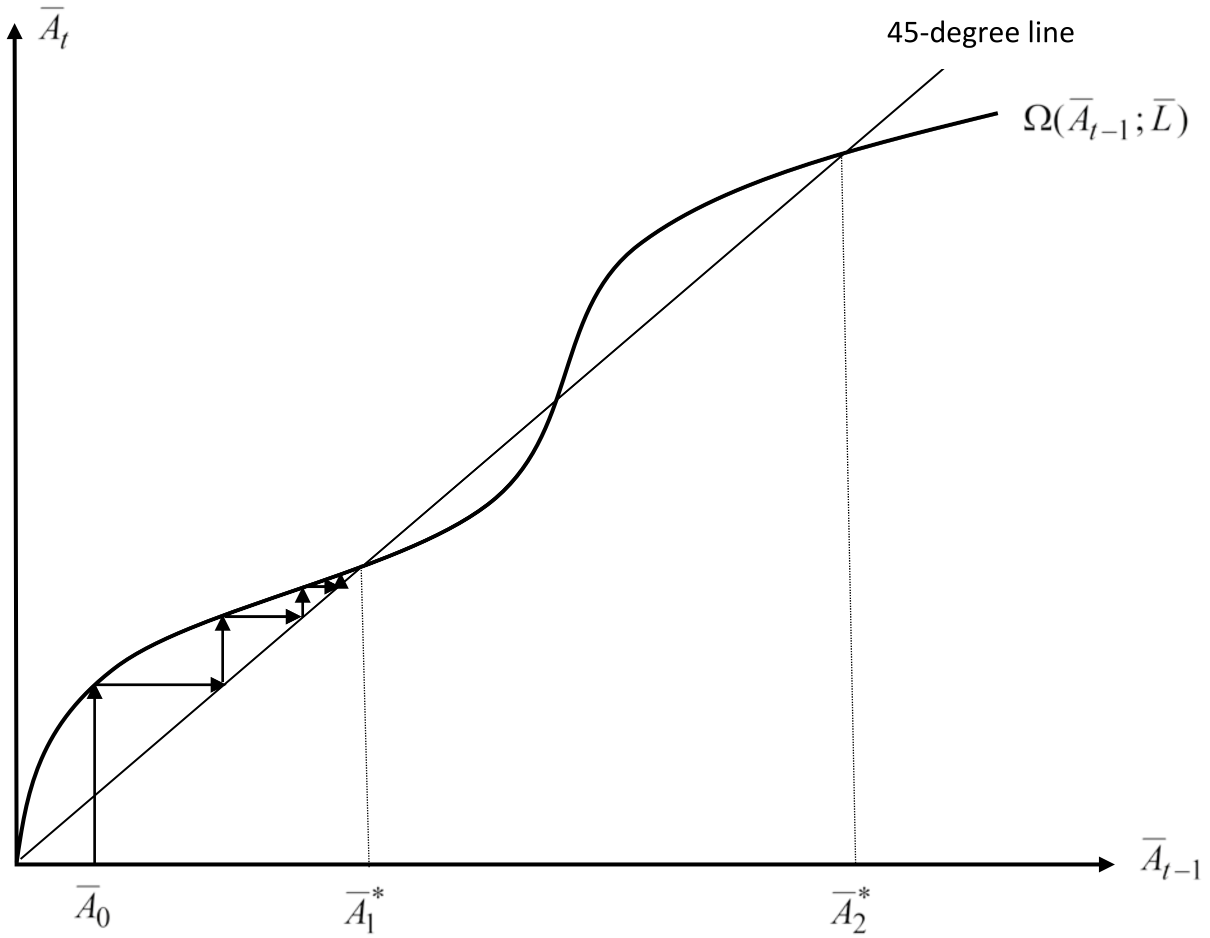
Proposition 2 suggests that the prospects for sustained economic growth are slim when structural change causes congestion effects. One should stress the role of cross-sectoral technology spillovers ($b' > 0$) and non-homothetic preferences ($\bar{c} > 0$) for the relationship between potential urban congestion effects and long-run economic growth in the model. Without positive R&D externalities from the industrial sector to the traditional sector ($b' = 0$) or if preferences are homothetic ($\bar{c} = 0$), advances in knowledge stock $\bar{A}$ do not cause structural change (Proposition 1), and therefore do not foster urban congestion effects (Corollary 1). Hence, there arises the possibility that, all other things being equal, long-run growth is sustained. However, in the case where $\bar{c} > 0$, we obtain the – at the first glance somewhat counterintuitive – insight that positive productivity externalities in favor of the traditional sector ($b' > 0$) may contribute to the end of economic growth in the long-run via congestion effects.

<INSERT Figure 1 here>

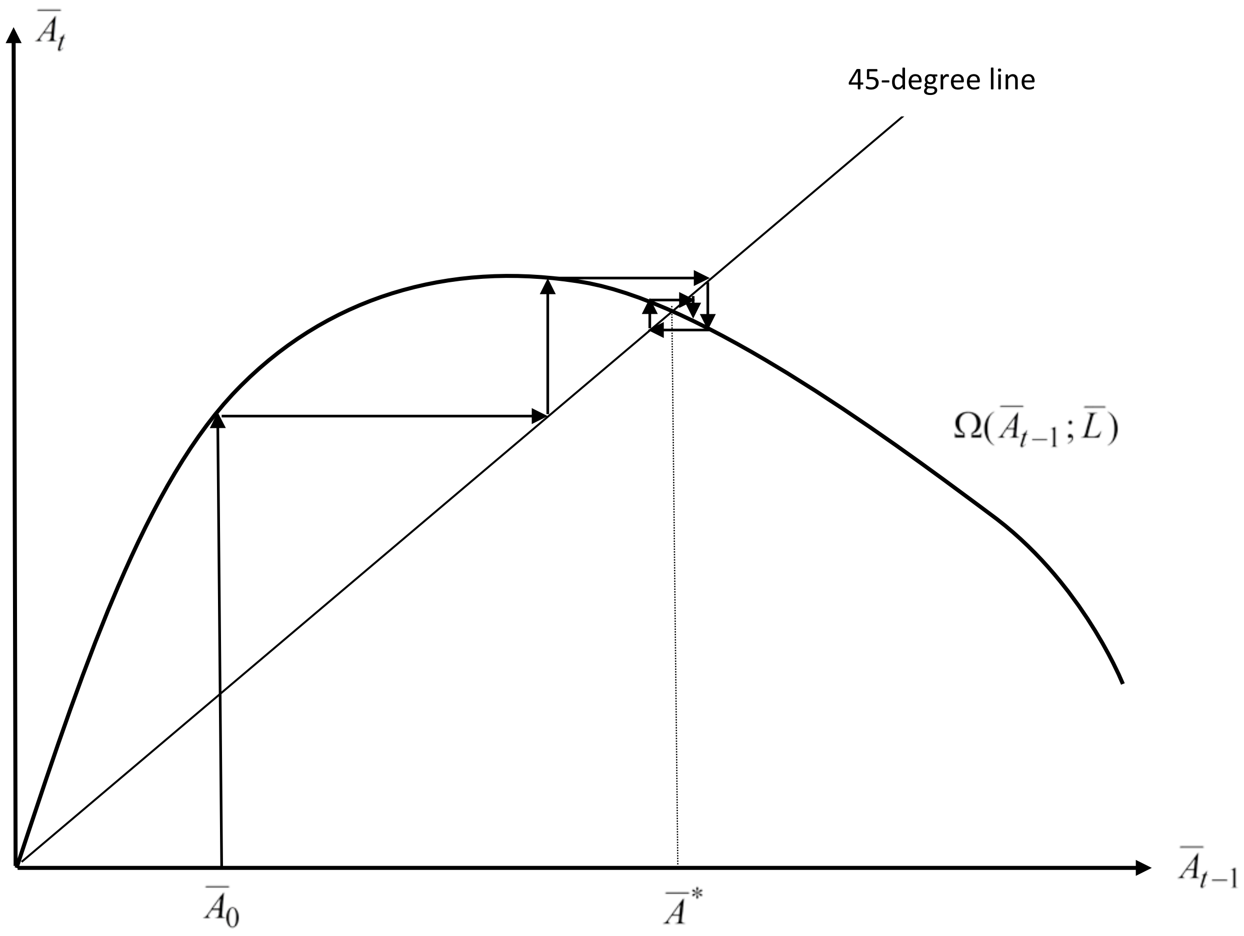
It is neither ensured that $\Omega(\bar{A}, \cdot)$ is increasing nor that it is concave as a function of $\bar{A}$. If not concave everywhere, multiple interior and stable steady states are possible.

[9] As is well known, long run growth is not sustainable if $\phi < 1$, even when there are no congestion effects. This would change if we allowed for population growth, like in Jones (1995).

Figure 1: Transitional dynamics to the steady state knowledge stock.



(a)



(b)

This is illustrated in panel (a) of Fig. 1, where both values $\bar{A}_1^*$ and $\bar{A}_2^*$ represent stable steady states.[10] In this case, the long-run position of the economy depends on the initial condition $\bar{A}_0$. Panel (b) of Fig. 1 shows a case where Ω is not everywhere increasing such that a cyclical adjustment to the steady state is conceivable.

Remark 1: Schultz (1985) presents empirical evidence on the effect of urbanization on demographic change. Endogenizing fertility is beyond the scope of the paper. However, to capture the feedback effect from urbanization to population size, suppose $\bar{L}$ is a (decreasing) function of the knowledge stock ($\bar{A}$). If $\bar{c} > 0$, the effect of change in $\bar{L}$ on urban population density $D_t = D^*(\bar{A}_{t-1}, \bar{L})$ is ambiguous (see the proof of Proposition 3). The reason is the following. If population size $\bar{L}$ declines over time, the fraction of labor devoted to manufacturing increases under non-homothetic preferences (Lemma 2). Thus, introducing a feedback effect from urbanization to population size does not necessarily mitigate congestion effects (as formalized in (9)) such that the pessimistic growth prospect may remain.

Remark 2: By contrast, allowing for public infrastructure investment may change the pessimistic outlook on long run growth. Suppose we would change the knowledge accumulation process (9) to

$$A_t(i) = \frac{(\bar{A}_{t-1})^{\phi}(G_{t-1})^{\kappa}}{(D_t)^{\theta}} h(l_t(i)), \tag{17}$$

$\phi, \theta, \kappa > 0$, where G is public infrastructure investment (fully depreciating each period, for simplicity). If G is an increasing function of the contemporaneous knowledge stock ($\bar{A}$), e.g. due to public financing from some kind of income taxation, then congestion effects may be sufficiently mitigated to restore long run growth.

3.2 Scale Effects and Dilution

The previous subsection has focused on congestion effects in the urban region due to endogenous technological progress which triggers structural change. In this subsection,

[10] Fig. 1 is drawn for the case of an interior steady states; otherwise, the economy converges to the trivial steady state, $\bar{A}^* = 0$.

we analyze the effects of higher population size ("scale") $\bar{L}$ on the per capita income level, y. Scale effects are an important issue in the literature on endogenous growth. As outlined in the introduction, the standard property that scale effects are positive is empirically questionable. The next result shows that, in the present context where urban land is an important factor for modern production, scale effects may even be negative.

Proposition 3: (Scale effects) *For given $\bar{A}_{t-1}$, an increase in population size $\bar{L}$ may cause a decline in per capita income (y_t) in both cases, $\bar{c} = 0$ and $\bar{c} > 0$.*

The intuition for Proposition 3 can be best seen by looking at scale effects on the wage rate, which equals the marginal product of labor in both sectors; for the manufacturing sector, $w = (1-\alpha)\frac{Y_M}{L_M}$. Since intermediate good firms are symmetric and thus choose the same amount of land in the urban area as input, we have $x(i) = \frac{\bar{Z}_M}{n}$ for all i. Using this in (8) we find that

$$w = (1-\alpha)\left(\frac{\bar{Z}_M}{L_M}\right)^{\alpha}\left(n\bar{A}\right)^{1-\alpha}. \tag{18}$$

An increase in scale $\bar{L}$ has several effects on the marginal product of labor, which result from a possible increase in total manufacturing employment, L_M. One effect, which gives rise to positive scale effects in standard endogenous growth models, is that the equilibrium number of intermediate good firms, n, increases with market size. In turn, due to specialization gains, productivity increases. However, at the same time, an increase in L_M triggers two negative effects on the wage rate. First, land input per worker in the manufacturing sector, $\bar{Z}_M/L_M$, declines; this has a dilution effect on the marginal product of labor in manufacturing. Moreover, urban population density increases. This lowers the contemporanous knowldge stock $\bar{A}_t$ due to congestion effects, in turn further depressing wages. As shown in the proof of Proposition 3, dilution effects alone may suffice to induce negative scale effects overall. Congestion effects from higher population size merely act as additional force.

4 Conclusion

This paper has examined the growth implications of urban congestion effects from endogenous structural change in a R&D-based growth framework with non-homothetic preferences and cross-sectoral technology spillovers. The analysis has demonstrated that urban congestion associated with structural change may leave economic growth unsustainable in the long-run. In the model, structural change was driven by Engel's law together with R&D-driven productivity advances which spill over to the traditional sector. Paradoxically, the analysis suggests that prospects of sustained long-run growth are mitigated by cross-sectoral productivity spillovers.

Moreover, this paper has addressed the long-standing debate on scale effects in the endogenous growth literature. We have shown that due to both a decrease in the urban land input per manufacturing worker (dilution effect) and congestion effects on manufacturing productivity, the impact of an increase in population size on per capita income may be negative.

Future research should incorporate into the model public infrastructure investment, which potentially mitigates urban congestion effects. This would allow us to look more closely at transitional dynamics. Such an extension would also enable us to investigate how the optimal path of productive public investment interacts with urban population density, which therefore could provide useful policy recommendations.

Appendix

Proof of Lemma 1: In the modern sector, the inverse demand schedule for intermediate good i is given by its marginal product $p(i) = \alpha(\frac{A(i)L_M}{x(i)})^{1-\alpha} \equiv P(x(i))$. (Recall that $p_M = 1$.) Monopoly profits of each firm i are given by

$$\pi_i = (p(i) - r_M)x_i - w_M(l(i) + f). \tag{19}$$

Profit-maximizing price-setting, when accounting for demand schedule $p(i) = P(x(i))$, leads to mark-up factor $\frac{1}{\alpha}$. Thus,

$$x_i = \left(\frac{\alpha^2}{r_M}\right)^{\frac{1}{1-\alpha}} A(i)L_M. \tag{20}$$

Using $p(i) = \frac{r_M}{\alpha}$, (20) and R&D technology (9) in (19), profits of firm i in t are given by

$$\pi_t(i) = (1-\alpha)\alpha^{\frac{1+\alpha}{1-\alpha}}(r_{Mt})^{-\frac{\alpha}{1-\alpha}} \underbrace{\frac{(\bar{A}_{t-1})^{\phi}}{(D_t)^{\theta}} h(l_t(i))}_{=A_t(i)} L_{Mt} - w_{Mt}(l_t(i) + f). \tag{21}$$

Now consider the R&D decision of intermediate good firms. Maximizing profits $\pi(i)$ in (21) with respect to $l(i)$ and observing (9) yields first-order condition

$$(1-\alpha)\alpha^{\frac{1+\alpha}{1-\alpha}}(r_M)^{-\frac{\alpha}{1-\alpha}} A_i \frac{h'(l(i))}{h(l(i))} L_M = w_M. \tag{22}$$

Moreover, from free entry equilibrium condition (ii) in Definition 1, $\pi(i) = 0$. Using (21) and (22), this implies that each firm i chooses a time-invariant R&D input as given by (12). Denote the right-hand side of (12) by $Q(l^*, f)$ and note that $\frac{\partial Q(l,f)}{\partial l} = \frac{h''(l)}{h'(l)} < 0$. Thus, l^* is unique; existence is ensured by the Inada conditions. ■

Proof of Lemma 2: The urban wage rate is given by the marginal product of labor in manufacturing, $w_M = (1-\alpha)\frac{Y_M}{L_M}$. Substituting (20) into (8) and using the resulting expression for Y_M leads to

$$w_M = (1-\alpha)\alpha^{\frac{2\alpha}{1-\alpha}}(r_M)^{-\frac{\alpha}{1-\alpha}} n\bar{A}. \tag{23}$$

Now combine (22) and (23), and then use $A(i) = \bar{A}$ and (12), to find that the number of intermediate good firms is given by

$$n = \frac{\alpha L_M}{l^* + f}. \tag{24}$$

Thus, $\tilde{L}_M = L_M + n(l^* + f)$ is given by

$$\tilde{L}_M = (1+\alpha)L_M. \tag{25}$$

According to (10), the value of the marginal product of agricultural labor is given by

$$w_A = Bp_A(1-\beta)\left(\frac{\bar{Z}_A}{L_A}\right)^{\beta}, \tag{26}$$

where we used equilibrium condition $Z_A = \bar{Z}_A$. Moreover, since intermediate good firms are symmetric, equilibrium condition (v) implies that $x(i) = \frac{\bar{Z}_M}{n}$ for all i. Thus, using (8), we have

$$Y_M = \left(\bar{Z}_M\right)^{\alpha}\left(n\bar{A}L_M\right)^{1-\alpha}. \tag{27}$$

Hence, wage rate $w_M = (1-\alpha)\frac{Y_M}{L_M}$ can be written as

$$w_M = (1-\alpha)\left(\frac{\bar{Z}_M}{L_M}\right)^{\alpha}\left(n\bar{A}\right)^{1-\alpha}. \tag{28}$$

Using (26), (28) and equilibrium condition $w_M = w_A$ yields

$$p_A = \frac{(1-\alpha)\left(\frac{\bar{Z}_M}{L_M}\right)^{\alpha}\left(n\bar{A}\right)^{1-\alpha}}{B(1-\beta)\left(\frac{\bar{Z}_A}{L_A}\right)^{\beta}}. \tag{29}$$

Using (5) and (6) in goods market clearing conditions (vi) and combining them by eliminating λ, we find that

$$p_A Y_A = \frac{1-\gamma}{\gamma}Y_M + \bar{L}\bar{c}p_A. \tag{30}$$

Substituting (10) and (27) into (30), and using $Z_A = \bar{Z}_A$, we obtain

$$p_A = \frac{1-\gamma}{\gamma}\frac{\left(\bar{Z}_M\right)^{\alpha}\left(n\bar{A}L_M\right)^{1-\alpha}}{B(\bar{Z}_A)^{\beta}\left(L_A\right)^{1-\beta} - \bar{L}\bar{c}}. \tag{31}$$

Next note that substituting (25) into labor market clearing condition, $\tilde{L}_M + L_A = \bar{L}$, implies that

$$l_M := \frac{L_M}{\bar{L}} = \frac{1 - l_A}{1 + \alpha}. \tag{32}$$

By combining (29) and (31) and using (32) we find that l_A^* is implicitly given by (13). According to (13), l_A^* is increasing in $\frac{\bar{c}}{B\left(\bar{Z}_A/\bar{L}\right)^{\beta}}$ and is equal to one if $\bar{c} = B\left(\frac{\bar{Z}_A}{\bar{L}}\right)^{\beta}$. Thus, under (A2), $l_A^* < 1$. Comparative-static results immediately follow. This concludes the proof. ■

Proof of Proposition 1: Immediately follows from the impact of an increase in B on l_A^* (Lemma 2) and $\frac{\mathrm{d}B_t}{\mathrm{d}A_{t-1}} > (=)0$ if $b' > (=)0$. ■

Proof of Corollary 1. Immediately follows from (14) and Proposition 1. ■

Proof of Proposition 2: For $\phi = 1$ and $\theta > 0$, we have $\varepsilon < 1$ if and only if $\bar{c} > 0$ and $b' > 0$. In this case, $\bar{A}_t = \bar{A}_{t-1} = \bar{A}^*$ when the $\Omega-$curve as shown in Fig. 1 crosses the 45-degree line. At $\bar{A}^*$ it may be the case that $\Omega_{\bar{A}}(\bar{A}^*, \cdot) \in (0, 1)$, $\Omega_{\bar{A}}(\bar{A}^*, \cdot) \in (-1, 0)$ or $\Omega_{\bar{A}}(\bar{A}^*, \cdot) < -1$, corresponding to gradual, cyclical or no adjustment to steady state level $\bar{A}^*$ over time, respectively. This confirms part (a). To prove part (b), first, substitute (14) into (15) to obtain

$$\bar{A}_t = (\bar{A}_{t-1})^{\phi} h(l^*) \left(\frac{\bar{Z}_M}{[1 - \tilde{l}_A^*(\bar{A}_{t-1}, \bar{L})]\bar{L}} \right)^{\theta}. \tag{33}$$

If $\bar{c} = 0$ or $b' = 0$, $\tilde{l}_A^*$ is independent of $\bar{A}_{t-1}$. Thus, for $\phi = 1$, $\bar{A}_t$ is proportional to $\bar{A}_{t-1}$. This concludes the proof. ■

Proof of Proposition 3: According to (20), land demand in manufacturing, $Z_M = \int_0^n x_i di$, is given by

$$Z_M = \alpha^{\frac{2}{1-\alpha}} (r_M)^{-\frac{1}{1-\alpha}} \bar{A} n L_M. \tag{34}$$

Since $Z_M = \bar{Z}_M$ in equilibrium, using $l_M = \frac{L_M}{\bar{L}}$, we find that

$$\frac{r_M \bar{Z}_M}{\bar{L}} = \alpha^2 \left(n\bar{A}l_M\right)^{1-\alpha} \left(\frac{\bar{Z}_M}{\bar{L}}\right)^{\alpha}. \tag{35}$$

The marginal product of rural land is given by

$$r_A = Bp_A\beta \left(\frac{\bar{Z}_A}{L_A}\right)^{-(1-\beta)}. \tag{36}$$

Substituting (29) into (36) and using $Z_A = \bar{Z}_A$, $l_A = \frac{L_A}{\bar{L}}$ and $l_M = \frac{L_M}{\bar{L}}$, we have

$$\frac{r_A\bar{Z}_A}{\bar{L}} = \frac{(1-\alpha)\beta}{1-\beta}\left(\frac{\bar{Z}_M}{l_M\bar{L}}\right)^{\alpha}\left(n\bar{A}\right)^{1-\alpha} l_A. \tag{37}$$

Moreover, according to (28) and $w = w_M$, we find

$$w = (1-\alpha)\left(\frac{\bar{Z}_M}{l_M\bar{L}}\right)^{\alpha}\left(n\bar{A}\right)^{1-\alpha}. \tag{38}$$

Next, denote the equilibrium value of l_M by l_M^* and note that

$$l_A^* = 1-(1+\alpha)l_M^*, \tag{39}$$

according to (32). Substituting 39) into (33) leads to

$$\bar{A}_t = (\bar{A}_{t-1})^{\phi}h(l^*)\left(\frac{\bar{Z}_M}{(1+\alpha)l_{M,t}^*\bar{L}}\right)^{\theta}. \tag{40}$$

Now substitute (35), (37) and (38) into (3) and use (24), (39) and (40) and to find that

$$y_t = (1-\alpha)\left(\frac{\alpha(\bar{A}_{t-1})^{\phi}h(l^*)}{(1+\alpha)^{\theta}(l^*+f)}\right)^{1-\alpha}\left(\bar{Z}_M\right)^{\alpha+(1-\alpha)\theta}\left[\frac{(\alpha^2-\beta)l_{M,t}^*}{1-\alpha}+\frac{1}{1-\beta}\right]\left(l_{M,t}^*\bar{L}\right)^{1-2\alpha-(1-\alpha)\theta}. \tag{41}$$

According to Lemma 1, l^* is independent of $\bar{L}$. If $\bar{c}=0$, l_M^* is independent of $\bar{L}$ as well, according to Lemma 2 and (32). Thus, for given $\bar{A}_{t-1}$, y_t is decreasing in $\bar{L}$ whenever $\alpha \geq 0.5$.

For $\bar{c} > 0$, $l_{M,t}^*$ is decreasing in $\bar{L}$, according to Lemma 2 and (32). Thus, if $\alpha^2 > \beta$, the term in squared brackets on the right-hand side of (41) is decreasing in $\bar{L}$. According to (32), $L_M^* := l_M^*\bar{L}$ is increasing in $\bar{L}$ if $\frac{\partial l_A^*}{\partial \bar{L}}\bar{L} < 1-l_A^*$. Using (13) and applying the implicit function theorem, this condition is equivalent to $\beta+(1+\chi)(1-\beta-l_A^*)l_A^* > 0$, which holds, for instance, if $1-\beta > l_A^*$. According to (13), $l_A^* \geq (1+\chi)^{-1}$. We thus need to check when $1-\beta > (1+\chi)^{-1}$ holds; or, equivalently, $\beta < \frac{\gamma(1-\alpha^2)}{1-\gamma}$. Also note from (13) that l_A^* is increasing in $\bar{c}$. Thus, if both β and $\bar{c}$ are low, it is possible that $1-\beta > l_A^*$. If, in addition, $\alpha \geq 0.5$, then the last factor on the right-hand side of (41) is decreasing in $\bar{L}$. This concludes the proof. ■

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