Agglomeration, Pollution, and Migration: A Substantial Link, and Policy Design

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9.1 Introduction

In 1800, urban residents accounted for about two percent of the world's population. In parallel with continued economic growth in the course of the next two centuries, the world's urban population has risen dramatically. Today, the majority of the world's population lives and works in cities. Urban production benefits from economies of scale, and rural-to-urban migration, the main contributor to urban population growth, is conducive to urban-based economic development (Ricardo, 1817; Lewis, 1955; Lucas, 2004). However, urbanization also brings in its wake environmental degradation which causes many ills and reduces the quality of (urban) life (Ray, 1998; Todaro and Smith, 2012). Walker and Tian (2015, p. 570) write: "In the nineteenth century, industrial cities were incredibly unhealthy places to live due to a combination of infectious diseases and pollution (Cain and Hong, 2009; Kesztenbaum and Rosenthal, 2011). Today, industrial cities in developing countries face similar challenges, particularly the threat of high pollution levels. For example, a World Health Organization (2014) report attributed 3.7 million premature deaths to ambient air pollution. Of these, about 88 percent occur in low and middle-income countries, chiefly in East and South Asia."

China offers a striking example of a combination of severe environmental problems and massive rural-to-urban migration. With some 240 million rural migrants living and working in China's cities, labor migration within China is the largest migration episode that the world has ever witnessed. Although this migration has been a driving force in China's economic expansion

(NBS, 2018), it has also caused substantial environmental problems. Zheng and Kahn (2013, pp. 731-732) write: "Based on an ambient particulate concentration criterion of PM10, twelve of the twenty most polluted cities in the world are located in China... . In 2003, 53 percent of the 341 monitored cities - accounting for 58 percent of the country's urban population - reported annual average PM10 levels above $100\,\mu g/m^3$,[1] and 21 percent of China's cities reported PM10 levels above $150\,\mu g/m^3$. Only one percent of China's urban population lives in cities that meet the European Union's air quality standard of $40\,\mu g/m^3$."

The many ills of industrial pollution in developing countries are well known: the contamination of drinking water and the release of toxins into the air are two examples. Water that comes into close contact with harmful chemicals, organic sludge, and radioactive waste, is poured into rivers. A recent report notes: "Shanghai, with its chic cafes, glitzy shopping malls and organic health food shops, is emblematic of improving quality of life for China's urban middle class. Yet while the city's veil of smog has lifted slightly in recent years, its water pollution crisis continues unabated - 85% of the water in the city's major rivers was undrinkable in 2015, according to official standards, and 56.4% was unfit for any purpose... . In Beijing, 39.9% of water was so polluted that it was essentially functionless. In Tianjin, northern China's principal port city and home to 15 million people, a mere 4.9% of water is usable as a drinking water source."[2] India does not fare much better. For example, in its December 8, 2019 issue, *The Economist* magazine cites estimates that 70% of the surface water in Delhi is tainted. Consumption of dirty water directly causes deaths, and contributes to slower killers such as kidney disease. Industrial pollution causes birth defects, worsens hygiene, and harms sanitation systems, which often leads to infectious diseases. Lamba and Subramanian (2020) attribute much of the environmental pollution in India to the country's rapid urbanization. As is well known, the overwhelming cause of this urbanization has been migration from the rural areas.

Two illuminating empirical studies on the interaction between environmental pollution and migration are provided by Bayer et al. (2009) and by Schoolman and Ma (2012). Based on a dataset about air quality in US metro areas in 1990 and 2000, Bayer et al. (2009) conduct a rigorous

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[1] $\mu g/m^3$ measures the concentration of an air pollutant in micrograms (one-millionth of a gram) per cubic meter of air.

[2] "In China, the water you drink is as dangerous as the air you breathe." Deng Tingting, *The Guardian*, June 2, 2017: https://www.theguardian.com/global-development-professionals-network/2017/jun/02/china-water-dangerous-pollution-greenpeace.

investigation into the impact of environmental pollution on the location and migration of households. They estimate that the elasticity of the willingness to pay with respect to air quality is between 0.34 and 0.42, implying that the median American household will be willing to pay \$149 to \$185 (in constant 1982-1984 dollars) for a one-unit reduction in average ambient concentrations of particulate matter. Schoolman and Ma (2012) find that in Jiangsu province, China, townships with larger populations of rural migrants are exposed to significantly higher levels of industrial pollution.

There is not much theoretical research on migration and pollution that is caused by urban production. Sandmo and Wildasin (1999) study optimal environmental taxation combined with migration quotas. With a focus on international migration, they do not address issues related to differences between urban and rural areas within a country. Quaas and Smulders (2018) analyze emissions taxes in a growth model in which workers can migrate between cities.

In this chapter we complement the existing literature in that we focus on distinct features that pertain to developing countries and on interaction between these features, which matter greatly in modeling and in policy design: presence of a substantial share of the population in the rural areas, large scale rural-to-urban migration, and heavy pollution in urban areas. In a general equilibrium model, we consider a two-sector economy in which urban production exhibits increasing returns to scale, whereas rural production exhibits constant returns to scale. An expansion of urban-based industrial production has the drawback of exacerbating pollution. Rural production, which does not generate pollution, is less efficient than urban production. We acknowledge that pollution can be local (affecting only urban individuals) or trans-boundary (affecting urban individuals and, to some extent, rural individuals as well).

Our model shows that under a laissez faire regime, namely in the absence of any government intervention, rural-to-urban migration may not increase social welfare. When electing to migrate to the cities, individuals do not consider the effect that their urban employment has in enhancing both urban agglomeration and industrial emissions. Thus, market equilibrium under a laissez faire regime rarely coincides with the social optimum. In a general equilibrium setting, as long as some individuals remain in the rural area, the level of utility of an urban individual is equal to the level of utility of a rural individual. Therefore, social welfare can be measured simply by the level of utility of a rural individual which, in turn, is determined by labor productivity in the rural area.

This perspective aligns with the dual economy model of Harris and Todaro (1970) and its further development by, among others, Shukla and Stark (1990), and Fan and Stark (2008). In the general equilibrium framework of these writings, the level of utility of an urban individual is equal to the level of utility of a rural individual. A typical assumption is that an individual derives utility from expected income. For example, Harris and Todaro (1970) argue that because of the high rate of unemployment in cities in developing countries, the expected income of an urban individual is equal to the rural wage rate. In our model, however, the equalizing variable of urban and rural levels of utility is urban pollution.

We study the effect of two policy interventions on industrial production, and we work out the consequences of the policy interventions for social welfare. What we find is that an emissions tax can increase industrial specialization (there will be more firms in the urban area) while it reduces each firm's output. This occurs because by itself, an increase in the extent of industrial specialization, which does not necessarily lead to the employment of more factors of production, has little environmental impact, whereas the reduction of output per firm lowers emissions. Holding the urban population constant, environmental regulation that curbs pollution levels can improve the welfare of urban individuals and, consequently, raise social welfare. However, when rural-to-urban migration is unhindered, an increase in the utility of urban individuals induces rural-to-urban migration. Because in equilibrium social welfare is a mirror image of the utility of a rural individual, an urban-targeted environmental policy does not on its own raise the utility of a rural individual. Thus, such a policy cannot increase social welfare in general equilibrium with endogenous migration. This conclusion differs from a stance in the existing literature (for example, Forslid et al., 2017) which studies emission taxes and agglomeration without considering though rural-to-urban migration and other unique features of developing countries.

A government can dole out to rural individuals a subsidy that is financed by taxing urban individuals. We characterize the optimal combination of a pollution tax and a subsidy to rural individuals. We show that when pollution is not trans-boundary, a subsidy to the rural area can lead to a Pareto improvement for the individuals in both the urban and the rural areas, thereby improving social welfare. When pollution is trans-boundary, simulation helps us specify conditions under which the subsidy increases social welfare, and it underscores that intervention will be more effective when the subsidy is combined with an environmental tax.

Aimed at narrowing the income gap between urban and rural individuals, subsidy programs to agriculture are widely used in both developing and developed countries. (As examples, consult Kirwan (2009) for the United States, Dorward and Chirwa (2011) for Malawi, and Du et al. (2011) for China.) Our analysis reveals that a possible unintended outcome of these programs can be to increase the welfare of urban individuals as well.

We organize our analysis in the following manner. In Section 9.2 we set up our basic analytical framework, and we characterize the equilibrium outcome of rural-to-urban migration under a laissez faire regime. In Section 9.3 we analyze the effect of an emissions tax levied on urban-based firms. In Section 9.4 we study a combined policy intervention of a subsidy to rural individuals and an urban emissions tax. In Section 9.5 we conclude.

9.2 Preferences, production, migration, and social welfare: the basic building blocks

In this section we model production, which takes place in the urban and rural sectors of the economy; we characterize individuals' preferences and endowments; we present the liking of rural people for migration to the urban sector; and we assess social welfare at the equilibrium rural-to-urban migration. The material in this section serves as infrastructure for the analysis that we carry out in the subsequent sections.

9.2.1 The individuals (the workers)

We consider an economy inhabited by Ω identical individuals whose preferences are represented by the utility function

$$V(c, D) = u(c) - v(D), \tag{9.1}$$

where c denotes the consumption of a single final good (consumption good) by an individual; D denotes the individual's exposure to environmental damage (pollution); and the differentiable functions u (of satisfaction) and v (of dissatisfaction) satisfy the conditions $u' > 0$, and

$$v' > 0, \quad v'' > 0, \quad v(0) = 0. \tag{9.2}$$

In (9.2), the first condition means that higher pollution causes higher disutility, the second condition informs us that in case of heavy pollution, the damaging effect of pollution will be increasingly penalizing, and the third condition implies that in a pollution-free environment, an individual does not experience disutility.

Every individual is endowed with one unit of labor, which is supplied inelastically in a perfectly competitive labor market. Individuals are free to choose in which sector to live and work.

The consumption good is produced either by rural producers who use a traditional clean (meaning pollution free) technology, or by urban firms that use a modern, dirty (meaning polluting) technology.[3] When urban production emits a total amount of pollution E, then the levels of environmental damage inflicted on urban individuals and rural individuals are

$$D = \begin{cases} E & \text{for the urban population} \\ \rho E & \text{for the rural population,} \end{cases} \tag{9.3}$$

where $\rho \in [0, 1)$ measures the external effect of urban-generated pollution on the rural population. If $\rho = 0$, then urban pollution is local, meaning that it does not spread to the rural area and thus does not affect the rural population. When $\rho > 0$, pollution is trans-boundary, meaning that it filters from the urban area to the rural area; the higher ρ, the higher the trans-boundary pollution.

9.2.2 Urban production: Agglomeration, and environmental pollution

Urban-based production is modeled as follows. The urban economy produces intermediate goods, and a final (consumption) good. Production of the intermediate goods is carried out by numerous firms. The market structure in which these firms operate is monopolistic competition, with free entry and with zero profit in equilibrium. Production of the consumption good takes place under constant returns to scale. Following Ethier (1982), we assume that this production is achieved by assembling a large number of intermediate goods (or by multiple processes). As such, in and of itself, assembly is costless.

In formalizing urban production, we draw on the analytical framework of Dixit and Stiglitz (1977), which is the bedrock of the extensive literature on increasing returns to scale and trade (consult Krugman, 1979, 1980) and of economic geography (consult Krugman, 1991). In this vein, we proceed as follows.

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[3] As an example, consider food preservation. Traditional methods (such as pickling, salting, and canning) do not pollute the environment, whereas freezing food in modern deepfreezes and refrigerators consumes energy and emits pollutants such as ozone-depleting gases.

The production technology of the final good exhibits constant returns to scale, where output is obtained from use of a given set of intermediate goods indexed by i. The production function is

$$X = \left(\sum_{i=1}^{n} x_i^{\theta} \right)^{\frac{1}{\theta}}, \tag{9.4}$$

where X and x_i denote, respectively, the quantity of the final good and the quantity of the i-th intermediate good, $i = 1, 2, \ldots, n$; n is the number of intermediate goods; and $\theta \in (0, 1)$ measures the degree of substitution in production between different intermediate goods.

Let P be the price of the final good, and let p_i be the price of the i-th intermediate good. The production of the final good is carried out in a perfectly competitive environment, meaning that the producers of the final good take the price, P, as given. The revenue of these producers is PX. The costs that they incur arises from the purchase of intermediate goods. Therefore, their profit, Π, is

$$\Pi = PX - \sum_{i=1}^{n} p_i x_i. \tag{9.5}$$

Given P and p_i, maximization of the profit in (9.5) with respect to x_i yields the following first order condition:

$$P \frac{1}{\theta} \left(\sum_{i=1}^{n} x_i^{\theta} \right)^{\frac{1}{\theta} - 1} \theta x_i^{\theta - 1} - p_i = 0 \quad \Leftrightarrow \quad x_i = \left(\frac{p_i}{P} \right)^{\frac{1}{\theta - 1}} X. \tag{9.6}$$

The second part of (9.6) is the demand function for the i-th intermediate good where, recalling that $\theta \in (0, 1)$, x_i and p_i are inversely related. Because, as noted above, the market of the final good is perfectly competitive, we can insert (9.6) into (9.5), and thereby express the zero profit condition $\Pi = 0$

$$PX = \sum_{i=1}^{n} p_i \left(\frac{p_i}{P} \right)^{\frac{1}{\theta - 1}} X \quad \Leftrightarrow \quad P = \left(\sum_{i=1}^{n} p_i^{\frac{\theta}{\theta - 1}} \right)^{\frac{\theta - 1}{\theta}}, \tag{9.7}$$

which shows that the price of the final good is a composite index of the prices of the intermediate goods.

As already noted, production of the intermediate goods is by firms that operate under monopolistic competition. As Krugman (1979) indicated, a firm will always switch to a different intermediate good rather than compete with another firm to produce the same intermediate good. In equilibrium, no intermediate good will be produced by multiple firms; each intermediate good will be produced by one monopolistic firm.

Each firm that produces an intermediate good employs labor as its only factor of production. Let $l_i, i = 1, 2, \ldots, n$ be the units of labor hired to produce the i-th intermediate good. Then, the production function of a producer of this intermediate good takes the form

$$l_i = \alpha + \beta x_i \tag{9.8}$$

where $\alpha > 0$ measures the fixed cost (the units of labor hired before production, say in order to construct and maintain the production facility), and $\beta > 0$ measures the marginal cost of producing a unit of the intermediate good.

The firm that produces the i-th intermediate good, $i = 1, 2, \ldots, n$, maximizes its profit

$$\pi_i = p_i x_i - w l_i = \left(p_i^{\frac{\theta}{\theta-1}} - \beta w p_i^{\frac{1}{\theta-1}} \right) P^{\frac{1}{1-\theta}} X - \alpha w. \tag{9.9}$$

A single firm, being small relative to the urban economy, ignores the effect of its choice of quantity of output on the price and on the total output of the final good (P and X, respectively). The profit-maximizing price, p_i, satisfies the following first order condition:

$$\frac{\theta}{\theta-1} p_i^{\frac{\theta}{\theta-1}-1} - \frac{1}{\theta-1} \beta w p_i^{\frac{1}{\theta-1}-1} = 0 \quad \Leftrightarrow \quad p_i = \frac{\beta w}{\theta}. \tag{9.10}$$

Assuming that firms are free to enter and exit the market, the profit derived from the production of the i-th intermediate good will be driven to zero, namely

$$\pi_i = \frac{\beta w}{\theta} x_i - w(\alpha + \beta x_i) = 0 \quad \Leftrightarrow \quad x_i = \frac{\alpha \theta}{\beta(1-\theta)}. \tag{9.11}$$

Equations (9.10) and (9.11) have two implications. First, firms are symmetric, charging the same price, as indicated by (9.10), and supplying the same quantity of intermediate goods, as indicated by (9.11). Second, the size of the urban population (or, for that matter, the extent of rural-to-urban migration) affects neither each firm's pricing strategy nor its scale of operations.

For an urban population (labor force) of size L, the full employment condition is

$$L = \sum_{i=1}^{n} l_i. \tag{9.12}$$

Inserting (9.11) into (9.8), we get an expression for l_i, which is subsequently inserted into (9.12). Then, we can solve the number of firms that produce the intermediate goods as

$$n = \frac{L}{\alpha + \beta x_i} = \frac{(1-\theta)L}{\alpha}, \tag{9.13}$$

which can serve as a measure of the degree of industrial specialization. Equation (9.13) implies that n decreases with α; the fixed cost limits the variety of intermediate goods.

We also note that n is proportional to L, which means that an increase in the urban population contributes to industrial specialization in production of the x_i intermediate goods. Inserting x_i in (9.11) and (9.13) into (9.4) yields the aggregate income (in terms of the final good) of the urban workforce

$$X = n^{\frac{1}{\theta}} x_i = \left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1} \frac{\theta L^{\frac{1}{\theta}}}{\beta}. \tag{9.14}$$

Because the goods produced in the urban area are consumed by the urban individuals, the level of consumption of each urban individual can be written as

$$c^b = \frac{X}{L} = \left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1} \frac{\theta L^{\frac{1}{\theta}-1}}{\beta}, \tag{9.15}$$

where the superscript b stands for "urban area."

Next, we assume that the production of an intermediate good generates pollution. In addition, and for simplicity's sake, we assume that the cost-free assembly of the intermediate goods into the final good yields no pollution. Suppose then that the emissions of pollution by firm i that produces intermediate good i is proportional to its scale of operations:

$$e_i = \gamma x_i, \tag{9.16}$$

where the parameter $\gamma > 0$ represents the emissions rate, namely the amount of emissions per unit of the intermediate good. Total emissions of pollutants in the urban area (for example, smog), which are a pure public bad, amount to

$$E \equiv \sum_{i=1}^{n} e_i = \frac{\gamma \theta L}{\beta}. \tag{9.17}$$

Inserting (9.15) and (9.17) into (9.1) yields the utility of an urban individual as a function of L:

$$V^b(L) = u\left[\left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1}\frac{\theta L^{\frac{1}{\theta}-1}}{\beta}\right] - v\left(\frac{\gamma\theta L}{\beta}\right). \tag{9.18}$$

9.2.3 Rural production

To begin with, we recall that there is only one consumption good in our model, and that in the urban area this good is produced using a large number of intermediate goods.

In the rural area, in contrast, the production process of the consumption good is "traditional," in the sense that it does not involve the use of intermediate goods; it employs only labor. The rural production function exhibits constant returns to scale, and it takes the simple linear form

$$Y = \phi R, \tag{9.19}$$

where Y and R denote, respectively, the aggregate rural output of the consumption good and the rural aggregate labor input. The parameter $\phi > 0$ represents labor productivity. With the economy-wide population size set as Ω, the number of rural individuals is

$$R = \Omega - L, \tag{9.20}$$

where $R \in (0, \Omega)$.

We assume that ϕ is sufficiently small, meaning that from a technological perspective, rural traditional production is relatively backward. With the production of the final good in the rural area taking place under perfect competition, the wage rate of a representative rural individual (in terms of the final goods) is also ϕ, and so is this individual's equilibrium level of consumption.[4] We have

$$c^r = \phi, \tag{9.21}$$

where the superscript r stands for "rural area."

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[4] We assume that rural inhabitants consume rural-produced goods, and that urban residents consume urban-produced goods. This assumption, which allows us to abstract from relating consumption in the rural areas to the price of goods produced in urban area and vice versa, helps us to avoid complicating the model for no real gain, and it has no bearing on our main results.

We also assume that rural production does not generate pollution. Nonetheless, when pollution caused by urban-based production is trans-boundary, rural individuals suffer from pollution. With the total level of urban-generated polluting emissions given in (9.17), drawing on (9.1) enables us to exhibit the utility of a rural individual as

$$V^r(L) = u(\phi) - v\left(\frac{\rho\gamma\theta L}{\beta}\right). \tag{9.22}$$

9.2.4 Rural-to-urban migration under a laissez faire regime, and social welfare

In this subsection we study the individuals' choice of location in the absence of government intervention. We analyze a case in which there is at least one individual in the urban area, and at least one individual in the rural area ($0 < L < \Omega$).

Rural-to-urban migration reaches equilibrium if and only if the condition $V^r(L) = V^b(L)$ is satisfied, namely if and only if the utility level (9.22) is equal to the utility level (9.18):

$$u(\phi) - v\left(\frac{\rho\gamma\theta L}{\beta}\right) = u\left[\frac{\theta}{\beta}\left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1} L^{\frac{1}{\theta}-1}\right] - v\left(\frac{\gamma\theta L}{\beta}\right). \tag{9.23}$$

We define the economy-wide utilitarian-based social welfare, $W(L)$, as

$$W(L) \equiv \frac{L}{\Omega}V^b(L) + \frac{\Omega - L}{\Omega}V^r(L). \tag{9.24}$$

When individuals migrate freely, then in equilibrium they obtain the same level of utility regardless of their location. Thus,

$$W(L) = V^b(L) = V^r(L). \tag{9.25}$$

Drawing on (9.23) and (9.25), we have the following proposition.

Proposition 1. *Under a laissez faire regime, the intensity of rural-to-urban migration*

(i) *does not affect social welfare when* $\rho = 0$;

(ii) *always damages social welfare when* $\rho > 0$.

Proof. By (9.23) and (9.25), the level of social welfare in equilibrium can be written as

$$W(L) = V^r(L) = u(\phi) - v\left(\frac{\rho\gamma\theta L}{\beta}\right). \tag{9.26}$$

(i) If $\rho = 0$, then by (9.2), $v(0) = 0$. Subsequently, by (9.26) social welfare is $W(L) = u(\phi)$ for any L, which is unaffected by rural-to-urban migration.

(ii) If $\rho > 0$, then $W(L) < W(0)$ holds for all $L > 0$ because from (9.2), $v' > 0$. It then follows that rural-to-urban migration lowers social welfare. Q.E.D.

In our modeling framework, urban production is more efficient than rural production. Proposition 1 implies that in spite of this greater efficiency, rural-to-urban migration may not be welfare-improving in equilibrium, given the absence of government intervention. Part (i) of Proposition 1 informs us that no-one will be better off if rural-to-urban migration is allowed to take place when pollution is local, and part (ii) of Proposition 1 discloses an even worse outcome: in a general equilibrium setting without environmental regulation and with trans-boundary pollution, unrestricted rural-to-urban migration will make everyone worse off. We note that the condition which is needed for this result to hold is that the urban area does not suck in the entire rural workforce. We re-emphasize that in our model the equalizing force of urban and rural utilities is the level of urban pollution. Empirical studies consistently document a substantial wage gap between the urban and the rural areas (consult, for example, Young, 2013, and Lagakos, 2020). Therefore, it stands to reason that non-pecuniary factors equalize the levels of utility of rural and urban individuals. In our setting, pollution is one such factor.

9.3 Environmental regulation in the presence of unhindered rural-to-urban migration

In this section we ask how the introduction of an environmental policy that regulates urban polluting activities reshapes the equilibrium outcomes of migration, output, and welfare. We consider a case in which the government curbs pollution by levying an emissions tax at a rate that is equal to a proportion $\tau_e > 0$ of the urban wage rate, and that it then returns the tax revenue to urban individuals in a lump-sum fashion. Thus, to produce the i-th intermediate good, firm i has to pay an emissions tax amounting to

$$t_i = (\tau_e w) e_i. \tag{9.27}$$

The government, and the individuals and the firms interact in a manner akin to a Stackelberg game. The government moves first, announcing the emissions tax rate τ_e which is set to maximize social welfare. After observing the government's policy, the individuals select their place of work, and the monopolistically competitive firms choose the profit-maximizing price of the intermediate goods.

In the presence of the emissions tax/environmental cost, the profit function (9.9) needs to be revised, taking the form

$$\pi_i = p_i x_i - w l_i - t_i = \left[p_i^{\frac{\theta}{\theta-1}} - (\beta + \gamma\tau_e) w p_i^{\frac{1}{\theta-1}} \right] P^{\frac{1}{1-\theta}} X - \alpha w. \tag{9.28}$$

Accordingly, from the first order condition of the optimum of (9.28), obtained upon differentiation with respect to p_i, we solve the profit-maximizing price of the i-th intermediate good as

$$p_i = \frac{\beta + \gamma\tau_e}{\theta} w. \tag{9.29}$$

Inserting (9.6), (9.27), and (9.29) into (9.28), we express the profit function as

$$\pi_i = \frac{(\beta w + \gamma\tau_e) x_i}{\theta} - (\alpha + \beta x_i) w - \gamma\tau_e x_i w. \tag{9.30}$$

Consequently, the quantity of the i-th intermediate good and the number of intermediate goods can be expressed, respectively, as

$$x_i = \frac{\alpha\theta}{(1-\theta)(\beta + \gamma\tau_e)}, \tag{9.31}$$

and as

$$n = \frac{L}{\alpha + \beta x_i} = \frac{(1-\theta)(\beta + \gamma\tau_e) L}{\alpha[\beta + (1-\theta)\gamma\tau_e]}. \tag{9.32}$$

The level of emissions in the urban area is

$$E = \gamma \sum_{i=1}^{n} x_i = \frac{\gamma\theta L}{\beta + (1-\theta)\gamma\tau_e}. \tag{9.33}$$

Given our assumption that the emissions tax is returned to the urban individuals, the level of consumption of a representative urban individual is

$$c = \frac{X}{L} = \frac{n^{\frac{1}{\theta}} x_i}{L} = \left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1} \frac{\theta\,(\beta + \gamma\tau_e)^{\frac{1}{\theta}-1}\, L^{\frac{1}{\theta}-1}}{[\beta + (1-\theta)\,\gamma\tau_e]^{\frac{1}{\theta}}}. \tag{9.34}$$

Drawing on (9.34) we formulate the following proposition.

Proposition 2. *An increase in the emissions tax reduces urban production and consumption. Namely* $\dfrac{dc}{d\tau_e} < 0$.

Proof. From (9.34) we get

$$\begin{aligned} \frac{dc}{d\tau_e} = \theta\left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1} L^{\frac{1}{\theta}-1} \Bigg\{ \gamma\left(\frac{1}{\theta}-1\right)(\beta+\gamma\tau_e)^{\frac{1}{\theta}-2}[\beta+(1-\theta)\gamma\tau_e]^{\frac{1}{\theta}} \\ -(1-\theta)\gamma\left(\frac{1}{\theta}\right)(\beta+\gamma\tau_e)^{\frac{1}{\theta}-1}\,[\beta+(1-\theta)\gamma\tau_e]^{\frac{1}{\theta}-2}\Bigg\} /[\beta+(1-\theta)\gamma\tau_e]^{\frac{2}{\theta}}. \end{aligned} \tag{9.35}$$

From (9.35), it follows that $\dfrac{dc}{d\tau_e} < 0$ if and only if

$$\begin{aligned} &\gamma\left(\frac{1}{\theta}-1\right)(\beta+\gamma\tau_e)^{\frac{1}{\theta}-2}[\beta+(1-\theta)\gamma\tau_e]^{\frac{1}{\theta}} \\ &\qquad < (1-\theta)\gamma\left(\frac{1}{\theta}\right)(\beta+\gamma\tau_e)^{\frac{1}{\theta}-1}[\beta+(1-\theta)\gamma\tau_e]^{\frac{1}{\theta}-2}, \end{aligned} \tag{9.36}$$

or if and only if

$$(1-\theta)[\beta+(1-\theta)\gamma\tau_e] < (1-\theta)(\beta+\gamma\tau_e). \tag{9.37}$$

Clearly, (9.37) always holds. Q.E.D.

The intuition underlying Proposition 2 is straightforward: an increase in the emissions tax increases firms' production costs, which reduces output and, hence, consumption.

We now identify the impact of an emissions tax on rural-to-urban migration. Substituting (9.33) and (9.34) into the utility function (9.1) yields, respectively, the level of utility of an urban individual and the level of utility of a rural individual as functions of (τ_e, L):

$$V^b(\tau_e, L) = u\left[\left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1}\frac{\theta L^{\frac{1}{\theta}-1}(\beta+\gamma\tau_e)^{\frac{1}{\theta}-1}}{[\beta+(1-\theta)\gamma\tau_e]^{\frac{1}{\theta}}}\right] - v\left[\frac{\gamma\theta L}{\beta+(1-\theta)\gamma\tau_e}\right], \tag{9.38}$$

$$V^r(\tau_e, L) = u(\phi) - v\left[\frac{\rho\gamma\theta L}{\beta+(1-\theta)\gamma\tau_e}\right]. \tag{9.39}$$

Rural-to-urban migration is in equilibrium if and only if the condition $V^r(\tau_e, L) = V^b(\tau_e, L)$ is satisfied:

$$\begin{aligned} u(\phi) - v\left[\frac{\rho\gamma\theta L}{\beta+(1-\theta)\gamma\tau_e}\right] \\ = u\left[\left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1}\frac{\theta L^{\frac{1}{\theta}-1}(\beta+\gamma\tau_e)^{\frac{1}{\theta}-1}}{[\beta+(1-\theta)\gamma\tau_e]^{\frac{1}{\theta}}}\right] - v\left[\frac{\gamma\theta L}{\beta+(1-\theta)\gamma\tau_e}\right]. \end{aligned} \tag{9.40}$$

For a given emissions tax rate τ_e, we can get a solution for L in (9.40). We can express this solution as $L = L(\tau_e)$, which suggests that the size of the urban population is determined endogenously, being affected by the environmental policy and, consequently, by rural-to-urban migration.

To maximize social welfare $W = V^r(\tau_e, L)$, the government sets the emissions tax in accordance with the following first order condition derived from the maximization of (9.39):

$$\begin{aligned} -v'\frac{\rho\gamma\theta L'(\tau_e)[\beta+(1-\theta)\gamma\tau_e] - \rho\gamma\theta L(\tau_e)(1-\theta)\gamma}{[\beta+(1-\theta)\gamma\tau_e]^2} &= 0 \\ \Leftrightarrow \quad \frac{L(\tau_e^*)}{L'(\tau_e^*)} - \tau_e^* &= \frac{\beta}{(1-\theta)\gamma}, \end{aligned} \tag{9.41}$$

where by τ_e^* we denote the optimal emissions tax as the solution to (9.41). The next proposition follows directly from (9.41).

Proposition 3. *If the government chooses an emissions tax that is marginally higher than τ_e^*, then urban population grows.*

Proof. With τ_e^* as the solution of (9.41), we express the second part of (9.41) as

$L'(\tau_e^*) = \dfrac{L(\tau_e^*)}{\dfrac{\beta}{(1-\theta)\gamma} + \tau_e^*} > 0$, which shows that $L(\tau_e^*)$ increases with τ_e^*.

Q.E.D.

If we were to totally differentiate the equilibrium condition of rural-to-urban migration (9.40) with respect to $L(\tau_e)$ and τ_e, we would get a rather complicated expression, which implies: (i) that urban environmental regulation affects the migration decisions of rural individuals; and (ii) that it is generally ambiguous whether the impact of an emissions tax on migration is positive or negative. If τ_e is close to zero, a marginal increase in τ_e will improve the urban environment, which tends to increase rural-to-urban migration. On the other hand, if τ_e is already very high, further increases in τ_e will lower urban production, which tends to reduce rural-to-urban migration.

Proposition 3 refers to a particular case in which the optimal emissions tax is chosen: if τ_e is chosen optimally, then a marginal increase in τ_e will intensify rural-to-urban migration. When the government introduces environmental regulation aimed at curbing urban pollution, rural people find the urban area a more attractive place to live and work, which induces higher migration.

We next assess the impact of environmental policy on the pattern of urban production. This is characterized by the following proposition.

Proposition 4. *The introduction of the optimal emissions tax*

(i) *reduces each firm's supply of intermediate goods*;

(ii) *increases the variety of intermediate goods.*

Proof. (i) Because (9.31) shows that x_i is a decreasing function of τ_e, we have $x_i(0) > x_i(\tau_e)$ for all $\tau_e > 0$.

(ii) For any $\tau_e^* > 0$, it follows from Proposition 3 that $L(\tau_e^*) > L(0)$ and, hence, we express (9.32) as

$$n(\tau_e^*) = \frac{1-\theta}{\alpha}\left[1 + \frac{\theta\gamma}{\beta/\tau_e^* + (1-\theta)\gamma}\right] L(\tau_e^*) > \frac{1-\theta}{\alpha} L(0) = n(0).$$

Q.E.D.

Proposition 4 informs us that an emissions tax discourages the production by each polluting firm and enhances industrial specialization. We note that the total level of pollution is proportional to nx, where x is the output of each intermediate good ($x = \sum_{i=1}^{n} x_i$). Due to the fixed cost of producing a new intermediate good, nx tends to decrease with n. Thus, concern about pollution leads to an increase of the number of intermediate goods along with a reduction in the output of each intermediate good.

Based on (9.41), we formulate the following proposition. This proposition is distinct from the parallel Proposition 1.

Proposition 5. *With unhindered rural-to-urban migration*

(i) *when* $\rho = 0$, *an emissions tax cannot improve social welfare*;

(ii) *when* $\rho > 0$, *the optimal emissions tax will improve social welfare if and only if*

$$\frac{L(\tau_e^*)}{\beta + (1-\theta)\gamma\tau_e^*} < \frac{L(0)}{\beta}. \tag{9.42}$$

Proof. (i) When $\rho = 0$, namely when urban pollution is local, social welfare $W = u(\phi)$ is in equilibrium, which is independent of τ_e.

(ii) When $\rho > 0$, the optimal emissions tax $\tau_e^* > 0$ improves social welfare if and only if

$$u(\phi) - v\left[\frac{\rho\gamma\theta L(\tau_e^*)}{\beta + (1-\theta)\gamma\tau_e^*}\right] > u(\phi) - v\left[\frac{\rho\gamma\theta L(0)}{\beta}\right].$$

Under the assumption $v' > 0$ in (9.2), the inequality above is satisfied if and only if $\frac{\rho\gamma\theta L(\tau_e^*)}{\beta + (1-\theta)\gamma\tau_e^*} < \frac{\rho\gamma\theta L(0)}{\beta}$, namely if and only if condition (9.42) holds. Q.E.D.

Keeping the urban population constant, environmental regulation that curbs urban pollution improves the welfare of the urban population and, consequently, improves social welfare. However, when rural-to-urban migration is unhindered, Propositions 5 and 3 reveal that an increase in the utility of urban individuals does not increase social welfare in equilibrium. Instead, it induces rural-to-urban migration. While this migration increases urban production, it also increases industrial emissions, which ultimately reduce social welfare due to the increasing marginal disutility from environmental pollution. The underlying logic of Proposition 5, like the underlying logic of Proposition 1, is that in equilibrium, the levels of the individuals' utilities have to be the same in the rural and urban areas; in equilibrium, social welfare is equivalent to the utility of a rural individual. Because in and of itself urban environmental policy does not increase the utility of a rural individual, which is determined by rural productivity and urban pollution if this pollution is trans-boundary, it cannot increase social welfare in equilibrium when labor migration is unhindered.

We next study a combination of environmental regulation and other government policies that can improve social welfare.

9.4 Environmental policy combined with subsidization of the rural population

In this section we show that combining environmental policy with subsidization of rural individuals is an effective means of increasing social welfare. A subsidy to rural individuals can take the form of direct cash transfers from the government, or it can take the form of support for rural development.

The source of the funding for the rural subsidy can be urban taxation. We assume now that the government imposes an emissions tax τ_e and a non-distortionary tax on the final good (tax on urban real income) at the rate of τ_x. It is easy to see that τ_x is essentially an income tax on urban individuals. The emissions tax is returned to the urban individuals as per Section 9.3, while the income tax is transferred to the rural individuals.

The underlying logic of introducing this urban-to-rural subsidy scheme is straightforward. Because in equilibrium rural utility is the same as urban utility, an effective policy has to increase the welfare of both rural individuals and urban individuals. In the preceding section we have seen that tackling the urban environmental problem cannot increase social welfare due to the ensuing increase in rural-to-urban migration. Therefore, we need to explore an alternative method that increases the utility of rural individuals directly, thereby nipping in the bud the incentive to migrate and, ultimately, increasing the utility of the urban individuals as well.

The Stackelberg type game between the firms and the government proceeds as follows. The government moves first announcing the urban area emissions tax rate and income tax rate. Then firms make decisions on production, and individuals make migration choices, both of which determine the size of the urban population. Given (τ_x, τ_e), rural-to-urban migration reaches equilibrium if and only if $V^r(\tau_x, \tau_e, L) = V^b(\tau_x, \tau_e, L)$, namely if and only if

$$
\begin{aligned}
& u\left(\frac{Y+\tau_x X}{R}\right) - v(\rho E) = u\left[\frac{(1-\tau_x)X}{L}\right] - v(E) \\
& \quad \Leftrightarrow \quad u\left[\phi + \frac{\tau_x}{\Omega - L}\left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1} \frac{\theta(\beta+\gamma\tau_e)^{\frac{1}{\theta}-1} L^{\frac{1}{\theta}}}{[\beta+(1-\theta)\gamma\tau_e]^{\frac{1}{\theta}}}\right] - v\left[\frac{\rho\gamma\theta L}{\beta+(1-\theta)\gamma\tau_e}\right] \\
& \quad = u\left[(1-\tau_x)\left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1} \frac{\theta(\beta+\gamma\tau_e)^{\frac{1}{\theta}-1} L^{\frac{1}{\theta}-1}}{[\beta+(1-\theta)\,\gamma\tau_e]^{\frac{1}{\theta}}}\right] - v\left[\frac{\gamma\theta L}{\beta+(1-\theta)\gamma\tau_e}\right].
\end{aligned}
\tag{9.43}
$$

The government seeks to maximize social welfare $W = V^r(\tau_x, \tau_e, L)$ subject to the constraint (9.43).

In the preceding sections we have shown that as long as in equilibrium some individuals remain in the rural area, the existence of the urban sector does not bring about an increase in social welfare, despite the higher production efficiency of the urban production relative to the rural production. As characterized by the following proposition, this result is altered when a policy of subsidizing rural individuals is introduced.

Proposition 6. *Suppose that* $\rho = 0$ (*urban pollution is local*). *If the government subsidizes rural individuals* ($\tau_x > 0$) *then, in comparison with the case in which production takes place only in the rural area, the existence of urban production increases social welfare.*

Proof. When $\rho = 0$, then $u(\phi)$ represents social welfare in the absence of rural-to-urban migration. Because migration leads to a positive level of urban production, namely $X > 0$, then for $\tau_x > 0$ we get $\phi + \dfrac{\tau_x X}{1 - L} > \phi$. And because $u' > 0$, migration results in social welfare becoming $W = u\left(\phi + \dfrac{\tau_x X}{1 - L}\right) > u(\phi)$, which means that social welfare improves.

Q.E.D.

Propositions 1 and 5 show that as a result of unrestricted rural-to-urban migration, social welfare in equilibrium is effectively determined by the utility of a rural individual, as long as some individuals remain in the rural area. Therefore, the high production efficiency of urban production relative to rural production may not automatically lead to higher social welfare. Proposition 6 shows that this dilemma can be resolved by subsidizing rural individuals. With the combination of two policies, namely a rural subsidy and an environmental tax, the government can strike an optimal balance between increasing production efficiency and protecting the environment in a general-equilibrium framework that takes into account rural-to-urban migration. As noted several times already, in equilibrium social welfare is equivalent to the utility of a rural individual. When rural-to-urban migration is unhindered, an effective policy aimed at increasing social welfare has to increase the welfare of rural individuals; a direct subsidy to rural individuals is an obvious policy instrument for achieving this goal. A careful design of the set of policies allows the government to simultaneously increase the welfare of both urban and rural individuals in equilibrium.

When $\rho > 0$, then in comparison with the case of rural production only, the existence of urban production, which leads to rural-to-urban migration, increases social welfare if and only if there exists a pair of τ_e and τ_x such that the utility of a rural individual who receives the benefits from urban subsidy and is subjected to the trans-boundary pollution of urban production, exceeds the utility of a rural individual when there is neither subsidy nor pollution. Namely there exists a pair of τ_e and τ_x such that:

$$u\left[\phi + \frac{\theta\left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1}\tau_x}{\Omega - L(\tau_e,\tau_x)} \cdot \frac{(\beta+\gamma\tau_e)^{\frac{1}{\theta}-1}L(\tau_e,\tau_x)^{\frac{1}{\theta}}}{[\beta+(1-\theta)\gamma\tau_e]^{\frac{1}{\theta}}}\right] - v\left[\frac{\rho\gamma\theta L(\tau_e,\tau_x)}{\beta+(1-\theta)\gamma\tau_e}\right] > u(\phi). \tag{9.44}$$

Drawing on parameter configurations as exhibited below, we consider it helpful to display the gist of (9.44) by means of a simulation. To this end, we let the utility function (9.1) take the following functional form:

$$V(c,D) = 25c - D^2, \tag{9.45}$$

and we assign values to the parameters in (9.44) as per Table 9.1.

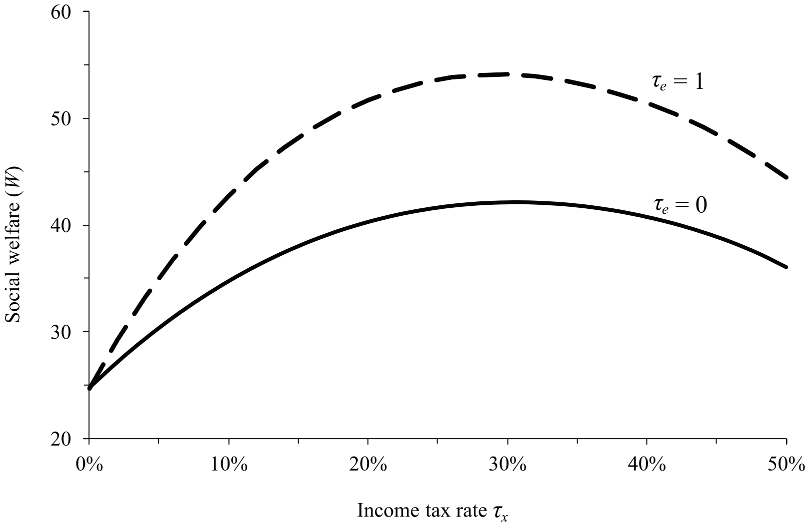
In Figure 9.1 we present curves that correspond to two values of the emissions tax: a curve that corresponds to $\tau_e = 0$, which is depicted by a solid line; and a curve that corresponds to $\tau_e = 1$, which is depicted by a dashed line.

Figure 9.1 fleshes out contrasting results of the welfare consequences of implementing a program of subsidizing rural individuals, financed by taxing the final good of urban production. As already noted, this tax is essentially an income tax on urban individuals. The solid curve portrays the relationship between social welfare and the tax rate τ_x for a case in which $\tau_e = 0$. When the subsidy is set at zero, that is, absent any government intervention, social

Table 9.1 Baseline parameter values in simulation of (9.44).

Parameter	Description	Value
α	Indicator of fixed cost of urban production	0.34
β	Indicator of variable cost of urban production	0.02
γ	The rate of generation of pollution	1
θ	The degree of substitutability between inputs	0.5
ϕ	Productivity of rural individuals	1
ρ	Degree of trans-boundary pollution	0.1
Ω	Population size	100

Figure 9.1 Income tax (τ_x), emissions tax (τ_e), and social welfare (W).



welfare is at 25. Social welfare rises continuously until the tax rate τ_x on the final good is set at about 30 percent, which yields social welfare at a level of about 41. The dashed curve portrays the relationship between social welfare and the tax rate τ_x for the case in which $\tau_e = 1$. Again, the lowest level of social welfare of 25 obtains when τ_x is set at zero. Social welfare rises continuously until the tax rate τ_x is set at about 30 percent, which yields social welfare at a level of about 55.

Thus, Figure 9.1 shows that a subsidy to rural individuals increases social welfare. When we compare the two curves in Figure 9.1 we see that the level of social welfare depicted by the dashed curve is generally higher than the level of social welfare depicted by the solid curve. In comparison with the case of only income tax, a combination of an environmental tax ($\tau_e = 1$) and an income tax improves social welfare.

The analysis in this section reveals that increasing the income of rural individuals is key to raising social welfare. The channels for achieving this can take the form of income transfers from the government to rural individuals or, alternatively, of increasing rural productivity and incomes through investment in productivity-enhancing rural infrastructure such as dams and systems of irrigation (a scheme studied, for example, by Ahlers and Schubert, 2009). To accommodate this possibility, we slightly extend the model, assuming that the government can use part of its revenue to improve rural infrastructure. Specifically, we assume that $\phi = f(t)$, where t is the government's investment in rural infrastructure, $f'(t) > 0$, $f''(t) < 0$. Then, the income of a rural individual will be $f(t) + s$, where s is the subsidy that a rural individual receives from the government.

Total government expenditure in the rural area, which consists of the cost of investment in rural infrastructure and the cost of the subsidy, is therefore $t + sR$. In this case, the budget constraint of the government is $t + sR = \tau_x X$. The government then needs to choose the best combination of t and τ so as to maximize social welfare, subject to the above budget constraint and the following new equilibrium condition of rural-to-urban migration:

$$\begin{aligned} & u\left[f(t) + \frac{1}{\Omega - L}\left\{\tau_x\left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1}\frac{\theta\,(\beta+\gamma\tau_e)^{\frac{1}{\theta}-1}\,L^{\frac{1}{\theta}}}{[\beta+(1-\theta)\,\gamma\tau_e]^{\frac{1}{\theta}}} - t\right\}\right] - v\left[\frac{\rho\gamma\theta L}{\beta+(1-\theta)\gamma\tau_e}\right] \\ & \quad = u\left[(1-\tau_x)\left(\frac{1-\theta}{\alpha}\right)^{\frac{1}{\theta}-1}\frac{\theta(\beta+\gamma\tau_e)^{\frac{1}{\theta}-1}L^{\frac{1}{\theta}-1}}{[\beta+(1-\theta)\gamma\tau_e]^{\frac{1}{\theta}}}\right] - v\left[\frac{\gamma\theta L}{\beta+(1-\theta)\gamma\tau_e}\right]. \end{aligned} \tag{9.46}$$

9.5 Conclusion

Models of rural-to-urban migration are at the heart of theories of development and economic growth. However, despite its prominence in the development economics literature, writing often ignores negative aspects of rural-to-urban migration such as the ensuing environmental pollution caused by the emissions from increased industrial urban production. Such an occurrence is a striking feature of industrialization at the early stages of development in most developed countries, and is still observed in many developing countries. Our analysis aims to fill this research gap by addressing the question how to tackle urban environmental pollution in the presence of substantial rural-to-urban migration. It also contributes to the growing literature that emphasizes the need to strike a balance between environmental protection and economic development so as to lead to sustainable development (Phaneuf and Requate, 2017).

We analyze the design of environmental policy in the context of rural-to-urban migration in a general equilibrium framework. In contrast with traditional, pollution-free rural production, urban production exhibits scale economies but causes environmental damage. Without government intervention, unhindered rural-to-urban migration enhances agglomeration and increases production efficiency, but it cannot improve social welfare due to the ensuing environmental degradation. In this setting, unrestricted rural-to-urban migration in developing countries leads to significant negative outcomes for all individuals, in the cities and in the countryside alike. Moreover, urban pollution problems cannot be resolved by environmental regulation alone. An emissions tax tends to mitigate pollution, but it will not raise social welfare because the improved urban environment will attract migrants and, consequently, the increase in urban production will generate more pollution and damage social welfare.

Therefore, a policy that can effectively improve social welfare has to find a way either of restricting rural-to-urban migration, or of subsidizing rural individuals. Our analysis shows that when there is no trans-boundary pollution, a subsidy to the rural area can lead to a Pareto improvement for the individuals in both the urban area and the rural area, which thereby raises social welfare. When there is no trans-boundary pollution, a simulation exercise fleshes out conditions under which a combination of an environmental tax and an income tax improves social welfare in comparison with the case of an income tax alone.

In follow up research, we could extend the chapter's modeling framework in order to incorporate the possibility of distributing industrial activities across cities. With no industrial pollution, the agglomeration effect is maximized when all the industrial activity is concentrated in a single megacity. However, this prescription will need to be modified upon acknowledging that greater industrial agglomeration leads to higher pollution. When the disutility from pollution increases with higher industrial emissions, the net social welfare effect of industrial concentration is ambiguous. We conjecture that under conditions to be specified, distributing industrial activities across multiple cities may increase social welfare in comparison with concentrating industrial production in a single megacity. Our analysis is based on a simplified static framework, which abstracts from the considerations of economic growth. From a dynamic perspective, it could be argued that with substantial technological development, urban pollution will be reduced overtime, which implies that an economy could be "asked" to tolerate more urban pollution at the early stages of economic development for the sake of growth that will eventually cause little pollution.

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