Green cities? Urbanization, trade and the environment*

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Preliminary and incomplete

March 27, 2013

Abstract

We study environmental pollution in an economic geography framework with two cities, where pollution arises from commuting within cities, goods transport between cities, production of manufacturing and agricultural goods, and residential energy use. We find that city size has an ambiguous effect on pollution levels. We also analyse how pollution changes with varying trade freeness, skilled wage income, and commuting costs.

JEL classification: Q5, R1

Keywords: environmental pollution, city structure

*We thank seminar participants in Kiel and Potsdam for helpful comments.

1 Introduction

The growth of cities and metropolises is one of the great secular trends in mankind. Economic historians document that the degree of urbanization, starting out from a level of about 9% at around 1300 has almost doubled in the wake of the Industrial Revolution and dramatically increased to 37,6% in 1990 (Bairoch, 1988, Table 31.1). Today, already more than half of the worlds population lives in cities and urban growth is expected to carry on, occurring most spectacularly in developing country megalopolises in recent times (Asian Development Bank, 2012; World Bank , 2009). Is this triumph of the city, as Edward Glaeser (2011) has put it, good or bad for the environment? The answer to this intriguing and pressing question is all but clear. Consider the following two facts. A breath-taking if problematic development, which has been recorded since the end of the 19th century and paralleled the rise of cities, is global warming, caused by carbon dioxide emissions and other greenhouse gases. It is also known, however, that a metropolis like New York City has seen its air pollution levels rise from 1800 to 1940 but then to fall again, reaching levels in 2000 which are below those in 1940 Kahn (2006).

A recent literature has started to explore the environmental effects of urbanization. One hypothesis holds that urban growth should ultimately be favourable for the environment since living in high density areas goes along with smaller housing lots and apartments and shorter driving distances to workplaces and for shopping (Glaeser 2011). Yet, pointing at the compactness of cities is insufficient to settle the issue, since increases in population density very likely go along with bigger cities, and hence more commuting, and since it is the entire urban system which is relevant, not cities in isolation (Gaigné, Riou and Thisse 2012). Moreover, the example of New York City already alluded to, suggests that there may be forces which induce cities to become dirtier at some stages of their development and greener at others, a behaviour which is termed the (urban) Environmental Kuznets Curve, EKC (Copeland and Taylor 2003; Kahn 2006).

The contribution of this paper is to offer a simple stylized theoretical framework which disentangles key forces driving an urban system and which allows us to establish hypothesis which should ultimately be helpful to guide future empirical work. Our framework has the following features. First, we build on the urban model of Alonso and we choose a utility specification such that the lot size chosen by households, and hence, the settlement density in cities is variable and endogenously determined. Second, the urban system consists of two cities whose size is determined by the market size effects (pecuniary externalities) established by the new economic geography (Fujita *et al.*, 1999). Third, in order to comprehend the key sources of environmental pollution, we include a housing sector, a farm sector and an industrial sector in the model. Fourth, we take local as well as global environmental externalities of housing, commuting and goods production and transport into account. Such an assumption is appropriate even in the context of the global warming since it is well-established that the sources of greenhouse gas emissions have negative local environmental effects. Three key parameters shape the space economy and the level and composition of emissions, trade costs, the productivity of skilled workers, and commuting costs. Total emissions increase or decrease depending on parameters. In our benchmark scenario, total emissions increase under agglomeration. Since the model predicts that agglomeration is induced when trade costs are reduced to intermediate levels and that redispersion of economic activity takes place under still lower trade costs, the emergence of an urban EKC becomes a distinct possibility. The concomitant income growth provides a counteracting force at low trade costs, however.

Our paper is related to several strands of the literature. First, there is a recent literature which has started to explore the nexus between urban growth and the environment both theoretically and empirically. Gaigne, Riou and Thisse (2012) develop a model of an urban system with two cities and extensions around a central business district in order to highlight that a compact city may not necessarily be environmentally-friendly when locations are endogenous and general equilibrium effects are taken into account. Our model is related to their model but differs in two key respects. First, the lot size is fixed in Gaigne et al. (2012) whereas we allow it to be endogenously determined. We see two advantages of our specification: it agrees with the empirical evidence and it allows us to study how the compactness of cities responds to key parameters. Second, we follow the new economic geography in considering an increasing returns manufacturing industry which produces a variety of different goods whereas their model has a homogeneous good. Tscharaktschiew and Hirte (2010) develop a spatial general equilibrium model of a single polycentric city and calibrate it according to an average German city in order to explore the effects of emission taxes and congestion charges on land-use and emissions. Their focus on a single city allows them to consider numerous urban details which we deliberately abstract from in order to zoom in an urban system consisting of two cities of endogenous size. Glaeser and Kahn (2010) provide an important recent empirical analysis which obtains supporting evidence for the view that American urban development is environmentally-friendly in the sense of being energy-efficient and carbon saving (Glaeser and Kahn 2010). Larson *et al.* (2012) provide related simulation analysis based on an Urban Energy Footprint Model which allows them to capture intricate and often unexpected feedback and rebound effects of energy policies that work through the urban land market.

Second, a small literature has addressed the interface between the environment and agglomeration from the point of view of the new economic geography. Calmette and Péchoux (2007) set up a suitable extension of the core-periphery model and study the implementation of an emission quota. They show that the quota reduces the environmental externality in the aggregate but this comes with the unexpected side-effect that agglomeration is induced at higher trade costs, already, which drives up environmental damage. Elbers and Withagen (2004) study the non-cooperative strategic choice of an environmental policy within a similar model and find that this stabilizes the symmetric equilibrium. Lange and Quaas (2007) use a footloose entrepreneur version of the core-periphery model to analyze how the distribution of economic activity in space is affected by local environmental pollution. They find that the extent of environmental damages determines whether symmetry, partial or full agglomeration of economic activity in space obtains. Following standard practice in the new economic geography, these works ignore urban extensions and urban costs altogether, features that we highlight in our analysis. Another difference is that these works do not allow the environmental externalities to be global.

Third, our paper is related to the research on the Environmental Kuznets curve which was initiated with the empirical work by Grossman and Krueger (1993, 1995) and which is surveyed in Dasgupta et al. (2002). A systematic theoretical exploration of the foundations of the EKC and its relation to international trade was then provided by Copeland and Taylor (2003). A recent strand of research has begun to explore the EKC from the point of view of cities and urban systems (Kahn 2006; Asian Development Bank 2012).

Finally, there are two important recent works which highlight the interface between cities and the environment from different angles. Cruz and Taylor (2012) explores the role of renewable energy sources which differ in the energy intensity for the size and density of urban agglomerations. Desmet and Rossi-Hansberg (2012) set up a dynamic spatial model which allows for trade costs, innovation and technology diffusion over space to study the impact of climatic change on spatial distribution of economic activity, trade and migration patterns as well as productivity and welfare. The calibrated version of the model shows that a main effect of global warming is to shift production and population to the north since regions in the north become warmer. Another important conclusion is that migration is extremely powerful to limit the costs of global warming.

The remainder of the paper is organized as follows. Section 2 lays out the model and establishes the long-run equilibrium. Our analysis which explores how key forces shape and determine the evolution of both the urban system and the emissions associated with different sources is performed in section 3. Section 4 offers some conclusions.

2 The model

We consider a model with two cities, two sectors (manufacturing/agricultural), and two types of workers (skilled/unskilled). Before describing the inter-city equilibrium, we derive expressions for the intra-city variables.

Consumers have utility

$$u = \mu \log C_M + \gamma \log C_H + (1-\mu-\gamma)\log C_A - E^{\theta}, \quad \theta > 0 \tag{1}$$

$$C_M = \left(\int_0^{N_1+N_2} c(s)^{(\sigma-1)/\sigma} ds\right)^{\sigma/(\sigma-1)} \tag{2}$$

where C_M is consumption of a composite manufacturing good, C_H consumption of housing (lot size), C_A consumption of agricultural goods, and E is the level of pollution, e.g. from greenhouse gas (GHG) emissions. N_i denotes the mass of varieties in city $i = 1, 2$ and $\sigma > 1$ is the elasticity of substitution.

All manufacturing workers commute to the central business district (CBD) to work. A worker who lives r km from the CBD incurs monetary commuting costs of tr. The household budget constraint is

$$w - tr = P_A C_A + \left(\int_0^{N+N^*} p(s)c(s)ds\right) + P_H C_H \tag{3}$$

where P_A and P_H denote the prices of the agricultural good and housing and $p(s)$ the price of variety s. Farmers don't commute (see below) and hence, their commuting cost is zero.

Maximizing utility subject to (3) gives the demand functions and indirect utility

$$C_M = \frac{\mu(w-tr)}{P_M}, \quad c(s) = \frac{p(s)^{-\sigma}\mu(w-tr)}{\int_0^{N+N^*} p(s)^{1-\sigma}ds} \tag{4}$$

$$C_H = \frac{\gamma(w-tr)}{P_H}, \quad C_A = \frac{(1-\mu-\gamma)(w-tr)}{P_A} \tag{5}$$

$$V = \log(w-tr) - \mu\log(P_M) - \gamma\log(P_H) - E^{\theta} \tag{6}$$

where $V \equiv \log v$, and $P_M = \left(\int_0^{N_i} p_{ii}(s)^{1-\sigma}ds + \int_{N_i}^{N_j} p_{ji}(s)^{1-\sigma}ds\right)^{1/(1-\sigma)}$ is the CES price index. The price per unit of variety s shipped from city j to i is denoted p_{ji}. We will use the A-good as the numeraire and set its price equal to one.

2.1 City structure

The city is linear and extends from 0 to r_2, the endogenous city border (we focus on the right side of the city only). There are two groups of workers, skilled (S) and unskilled (U). Unskilled may work in manufacturing or agriculture. They are immobile across cities but mobile between sectors. Skilled workers work in manufacturing only. All manufacturing workers commute to the CBD to work. We assume that farm workers live outside of the city boundary and don't commute.

Solving (6) gives consumers' bid rent function, i.e. the maximum amount a household living r km from the CBD would pay per square meter of land:

$$P_H(r) = e^{-E^{\theta}/\gamma} P_C^{-\mu/\gamma} \upsilon^{-1/\gamma} (w^j - tr)^{1/\gamma}, \quad j = S, U \tag{7}$$

The bid rent declines with distance from the CBD to compensate for higher commuting costs.

In equilibrium, the bid rent of the low skilled is steeper than that of the high skilled. This is due to the fact that commuting costs are assumed identical for both groups, but, since the income elasticity of housing demand is one with Cobb-Douglas utility, in equilibrium the high skilled consume more housing. Hence, they benefit more from low rents available in the suburbs. Therefore, the low skilled live in the city center and the high skilled in the suburbs (see Fig. 1).

We assume that farmers just bid the value of agricultural profits, R_A, for the land they live on. Moreover, they live on equally sized lots (since they don't commute, all farmers face the same price for housing) just outside of the city border r_2.

The city equilibrium is defined by the following equations:

$$\begin{aligned}
P_H^U(r_1) &= e^{-E^{\theta}/\gamma} P_C^{-\mu/\gamma} \upsilon_U^{-1/\gamma} (w_U - tr_1)^{1/\gamma} = P_H^S(r_1) && (8)\\
&= e^{-E^{\theta}/\gamma} P_C^{-\mu/\gamma} \upsilon_S^{-1/\gamma} (w_S - tr_1)^{1/\gamma} \\
P_H^S(r_2) &= e^{-E^{\theta}/\gamma} P_C^{-\mu/\gamma} \upsilon_S^{-1/\gamma} (w_S - tr_2)^{1/\gamma} = R_A && (9)\\
P_H^U &= e^{-E^{\theta}/\gamma} P_C^{-\mu/\gamma} \upsilon_U^{-1/\gamma} w_A^{1/\gamma} = R_A && (10)\\
N_U &= \int_0^{r_1} \frac{1}{C_H^U(\cdot)} dr = \frac{E^{-e^{\theta}/\gamma} P_C^{-\mu/\gamma} \upsilon_U^{-1/\gamma} (w_U^{1/\gamma} + (tr_1 - w_U)^{1/\gamma})}{t} && (11)\\
N_S &= \int_{r_1}^{r_2} \frac{1}{C_H^S(\cdot)} dr = \frac{E^{-e^{\theta}/\gamma} P_C^{-\mu/\gamma} \upsilon_S^{-1/\gamma} ((w_S - tr_1)^{1/\gamma} + (tr_2 - w_S)^{1/\gamma})}{t} && (12)
\end{aligned}$$

At r_1, the bid rent of the low-skilled equals that of the high-skilled. Second, at the city

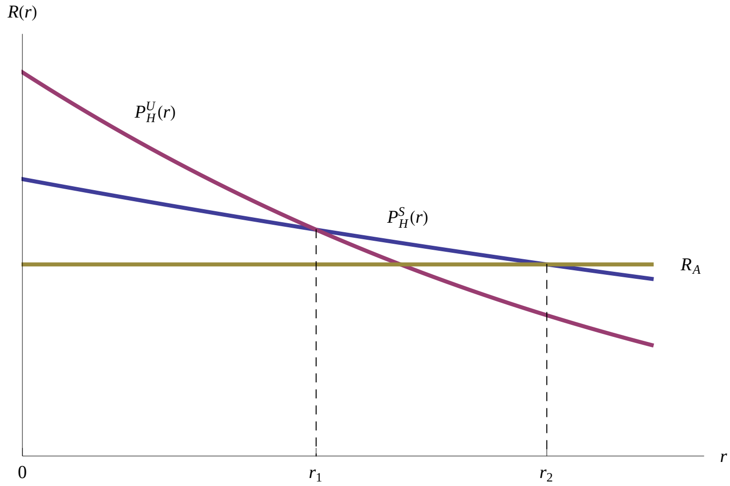

Figure 1: City equilibrium

border r_2, bid rent of the high skilled equals the agricultural rent R_A. Third, farm workers bid the agricultural land rent, R_A, regardless of their location. (11) and (12) say that the unskilled manufacturing workers fit into the area between the CBD and r_1 and the high skilled fit into the area between r_1 and r_2, given their housing demands.

Let w_A denote the agricultural wage. Solving (8)–(12) gives

$$v_U = e^{-E^\theta} P_C^{-\mu} R_A^{-\gamma} w_A \tag{13}$$

$$v_S = e^{-E^\theta} P_C^{-\mu} R_A^{-\gamma} (R_A^\gamma w_S + ((R_A + tN_S)^\gamma - (R_A + t(N_S + N_U))^\gamma) w_A) \tag{14}$$

$$r_1 = \frac{R_A^{-\gamma}((R_A + t(N_S + N_U))^\gamma) w_A - (R_A + tN_S)^\gamma}{t} \tag{15}$$

$$r_2 = \frac{(R_A + tN_S)^{-\gamma}((R_A + tN_S)^\gamma (w_S - w_A) - R_A^\gamma w_S + (R_A + t(N_S + N_U))^\gamma w_A)}{t} \tag{16}$$

$$w_U = R_A^{-\gamma}(R_A + t(N_S + N_U))^\gamma \tag{17}$$

For both groups, equilibrium utility in a city is decreasing in pollution, agricultural land rent, and the manufacturing price index. For skilled workers, equilibrium utility is also increasing in skilled wages, and decreasing in the size of the manufacturing work face – which drives up land rents – and commuting costs. For unskilled workers, utility increases in the agricultural wage but is independent of the city population and of commuting costs. This is so because they have the option to work in the agricultural sector, where there is no commuting. Note also that our model differs from Forslid and Ottaviano (2003) since agricultural workers do not earn the same wage as unskilled manufacturing workers. This is due to the assumption that farmers enjoy lower housing and commuting costs. The wage of manufacturing workers thus has to compensate for higher urban costs.

Equations (15) and (16) show the repercussions on city structure. In particular, in line with the standard Alonso model, we find that cities expand spatially when agricultural land rent or commuting costs fall, and when the skilled work force or skilled or unskilled wages rise.

Denote by $D(r) = 1/C_H(r,\cdot)$ the equilibrium density at distance r.

2.2 Production and short-run equilibrium

The agricultural sector produces a homogeneous good under constant returns to scale and perfect competition with unskilled labour as the sole input. Since this good is used as the numeraire, the agricultural wage is unity, $p_A = w_A = 1$.

The manufacturing sector produces differentiated goods under increasing returns and monopolistic competition. A manufacturing firm needs one skilled worker as fixed input and β units of unskilled labour per unit of output produced. We can think of skilled labour as producing managerial overhead, and let their productivity in producing this overhead be $1/\alpha$. Total cost for firm i is then

$$TC_i(s) = \alpha w_i^S + \beta w_i^U x_i \tag{18}$$

The number of manufacturing firms is $N_i = L_i^S$, with L_i^S being the skilled work force. Each firm produces one variety.

Firm profits are

$$\pi_i(s) = p_{ii}(s)d_{ii}(s) + p_{ij}(s)d_{ij}(s) - \beta(d_{ii}(s) + \tau d_{ij}(s))w_i^U - \alpha w_i^S \tag{19}$$

Maximizing firm profits gives the optimal prices

$$p_{ii}(s) = \frac{\beta\sigma}{\sigma-1}w_i^U, \quad p_{ij}(s) = \tau\frac{\beta\sigma}{\sigma-1}w_i^U \tag{20}$$

The price indices are given by

$$P_i^C \;=\; \frac{\beta\sigma}{\sigma-1}(N_i(w_i^U)^{1-\sigma} + \phi N_j(w_j^U)^{1-\sigma})^{1/(1-\sigma)} \tag{21}$$

where $\phi \equiv \tau^{1-\sigma}$ is the level of trade freeness.

The zero profit condition implies that the excess of revenue over operating costs, $(p_i -$

$\beta w_i^U)x_i$, just equals the fixed cost, αw_i^S. Using (20), this implies

$$w_i^S = \frac{\beta x_i}{\alpha(\sigma - 1)} w_i^U \tag{22}$$

Together with the market clearing condition $x_i = d_{ii}(s) + \tau d_{ij}(s)$ we get

$$\alpha \sigma w_i^S \quad = \quad \frac{\mu}{w_i^U} \left(\frac{Y_i}{N_i + \phi W^{1-\sigma} N_j} + \frac{\phi Y_j}{\phi N_i + W^{1-\sigma} N_j} \right) \tag{23}$$

where $W \equiv w_j^U / w_i^U$ and local incomes are given by

$$Y_i = w_i^S L_i^S + w_i^U L_i^{U,M} - t\bar{r}_i + (L_i^U - L_i^{U,M}) \tag{24}$$

where $\bar{r}_i$ is average commuting distance, $L_i^{U,M}$ is the number of unskilled manufacturing workers and L_i^U the total number of unskilled workers in city i. Together with $N_i = L_i^S$, (24) and (23) can be solved for w_1^S and w_2^S as functions of N_1.

The number of unskilled workers in manufacturing in city i is given by

$$L_i^{U,M} = N_i \beta x_i = N_i \alpha(\sigma - 1) \frac{w_i^S}{w_i^U} \tag{25}$$

We solve this equation numerically for $L_1^{U,M}$ and $L_2^{U,M}$ as functions of N_1. Using the resulting functions and the expressions for w_i^S and substituting in (14) gives the utility of skilled workers in city i, $v_i^S(N_1)$.

To ensure that the agricultural good is produced in both regions, we will restrict parameters such that in equilibrium, $L_i^{U,M} < L_i^U$ in both regions.[1]

2.3 Pollution

Pollution in city i takes the form

$$E_i = \delta_i E_{ii} + \delta_j E_{ij}$$

where E_{ii} is local pollution and E_{ij} cross-border pollution. For some pollutants, such as particulate matter, pollution may be purely local while at the other extreme GHG pollution

[1]Usually, one can restrict parameters by setting $N_1 = 1$ and solving $N_i \beta x_i = N_i(\sigma - 1) w_i^S < L_i^U$ for μ. However, in our model this gives a critical level of μ which depends on the number of unskilled manufacturing workers, which is endogenous. Hence, in the numerical simulations we check whether the chosen μ is below the critical level.

is truly global.

We consider pollution from different sources. Production of the manufacturing goods creates pollution through emissions. Commuting and shipping of import goods produces emissions from transport by cars and trucks. Finally, housing produces emissions from energy use due to electricity, heating and air conditioning. Total local pollution in city i is

$$E_{ii} = \delta_1 X_i + \delta_2 X_i^A + \delta_3 (C_i + T_i) + \delta_4 H_i$$

Production of the manufacturing good is given by:

$$X_i = N_i x_i \qquad (26)$$

$$x_i = \alpha\sigma \frac{w_i^S}{w_i^U} \qquad (27)$$

Agricultural production is:

$$X_i^A = N_i^U - \alpha(\sigma - 1) N_i \frac{w_i^S}{w_i^U} \qquad (28)$$

Total commuting km travelled in city i are:

$$C_i = \int_0^{r_2^i} tr D_i(r) dr \qquad (29)$$

Transport costs for traded goods are given by $(\tau - 1)$ times import demand:

$$T_i = (\tau - 1) D_{ij} = \frac{(\tau - 1)\tau^{-\sigma}}{w_j^U} \frac{\mu Y_i}{N_i W^{1-\sigma} + \phi N_j} \qquad (30)$$

Finally, aggregate housing in city i is given by:

$$H_i = \int_0^{r_1^i} C_H^U(r, \cdot) D(r, \cdot) dr + \int_{r_1^i}^{r_2^i} C_H^S(r, \cdot) D(r, \cdot) dr + (N_i^U - N_i^{U,M}) C_H^{U,A} \qquad (31)$$

$$= r_2^i + (N_i^U - N_i^{U,M}) C_H^{U,A} \qquad (32)$$

2.4 Long-run equilibrium

The long rund equilibrium is found by solving for the location choice of skilled workers.

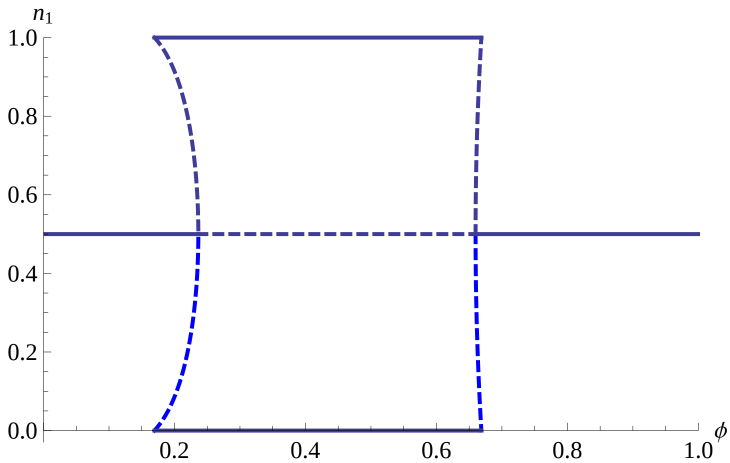

Figure 2: Bifurcation diagram

The migration of skilled workers is described by the 'ad hoc' dynamics

$$\dot{N}_1 = (v_1^S - v_2^S)N_1(1 - N_1) \tag{33}$$

An equilibrium is either given by dispersion, $N_1 = 1/2$ or partial agglomeration $1/2 < N_1 < 1$, if skilled worker utility is equalised across locations, or by full agglomeration, $N_1 = 1$, if all workers prefer to live in city 1.[2]

This model contains the well known agglomeration and dispersion forces as in Krugman (1991) and Forslid and Ottaviano (2003). In addition, urban costs (i.e. commuting costs) act as a deglomerative force (see Tabuchi, 1998; Murata and Thisse, 2005).Furthermore, environmental externalities may act as deglomerative force if $\delta_1 > \delta_2$ (see Lange and Quaas, 2007).

We solve (25) for the number of unskilled workers in region i as a function of the number of firms, N_1. We then use this to solve the utility differential $v_1^S - v_2^S$ for N_1.

Fig. 2 displays the bifurcation diagram, which shows the stable (solid lines) and unstable equilibria (dashed lines) for particular parameters.

An important question is whether big or small cities produce more emissions and consequently, whether agglomeration or dispersion of economic activity is environmentally more desirable. Increasing city population increases residents' average commuting distance. Hence, agglomeration increases emissions from commuter transit. The effect on goods transport is more intricate. Increasing city population decreases transport costs for

[2]Of course, there are the analogous equilibria with partial or full agglomeration in city 2.

imported varieties in that city. Conversely, decreasing city size increases transport costs. For the parameters in our benchmark scenario, total transport costs are actually higher with full agglomeration. This differs from Gaigné *et al.* (2012) who find that transport costs are lower with agglomeration. The difference is that in their model there are no immobile workers to whom goods have to be shipped in the case of full agglomeration. We further find that agglomeration decreases aggregate emissions from manufacturing production and increases emissions from agricultural production. Lastly, increasing city size reduces average dwelling sizes because of the increase in housing market competition. Hence, agglomeration decreases emissions from residential heating and electricity use.

3 Comparative statics

We now conduct three experiments. We first vary the degree of trade freeness to see how it affects emissions from the different sources. This can be linked to the large literature on trade and the environment (Copeland and Taylor, 2003). Second, we vary $1/\alpha$, the productivity of skilled workers. This parameter acts to exogenously increase the skilled wage. This effect can be linked to the equally large literature on the 'Environmental Kuznets curve' (Dasgupta *et al.*, 2002). And third, we vary commuting costs.

The effects of increasing trade freeness are shown in Figures 3–8. Note that trade freeness has a direct effect only on emissions from goods trade: trade costs first rise and then fall with the rise in ϕ. Otherwise, trade freeness affects emissions only indirectly via its effect on agglomeration. For a middle range of trade freeness, economic activity is agglomerated, while for low or high trade freeness activity is dispersed. The figures visualize the effects that were described in the last section: agglomeration, relative to dispersion, increases commuting and goods transport costs, decreases manufacturing production and increases agricultural production and decreases aggregate housing. Depending on parameters, total emissions may increase or decrease. For the parameters we use in our benchmark scenario, total emissions are higher with agglomeration than with dispersion. Overall, emissions follow an inverted U-shape in rising trade freeness. This is due to the dominating effect of transport costs.

Second, we vary α to study effects of increasing skilled wages. Figure 9 shows the bifurcation diagram for varying $1/\alpha$. Agglomeration occurs when the managerial efficiency is large.

Figures 10–15 show the effect of increasing skilled labour income on the various emission sources. Note that skilled income has a direct effect on most of these sources. When

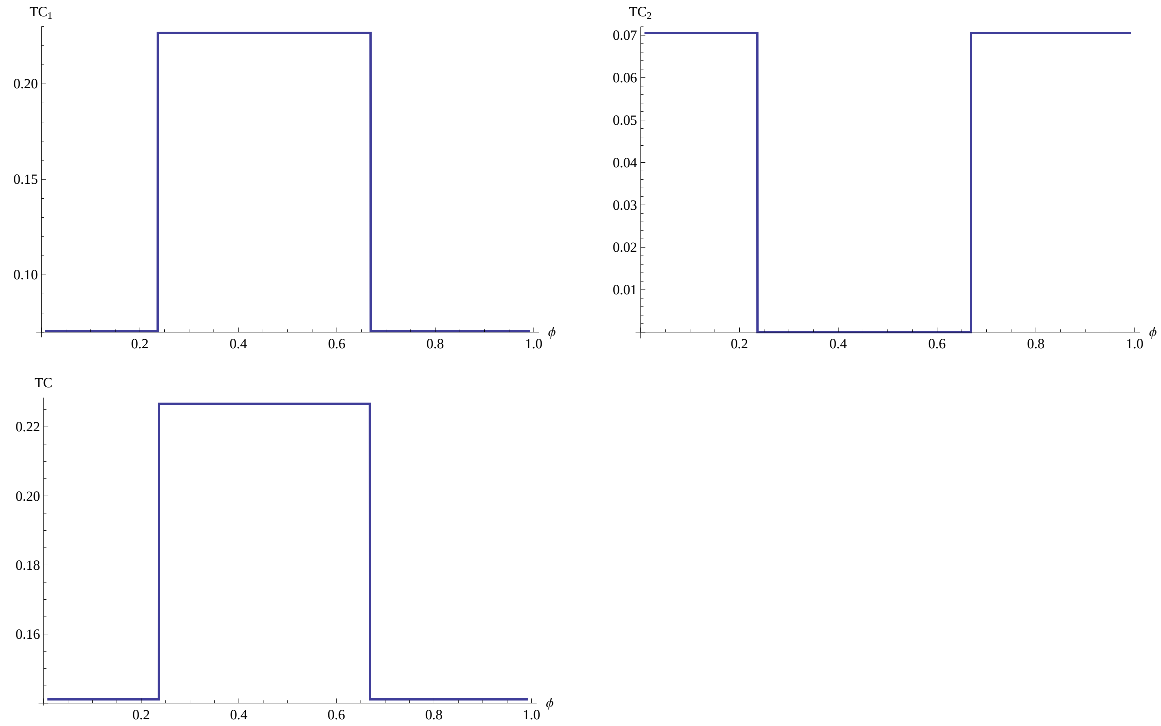

Figure 3: Pollution and trade freeness (commuting)

income increases, demand for industrial goods rises which increases production. This effect leads to a rise in the demand of unskilled labour and a reallocation from agriculture towards industry, so agricultural production falls. The increased demand for manufacturing output also leads to an increase in imports, which raises emissions from goods transport. Rising income also increases the demand for housing. Consequently, cities spread out, and commuting distances and demand for residential heating and electricity rise.

Third, we vary commuting costs. Fig. 16 shows that full agglomeration obtains when commuting costs are low. This is intuitive, as commuting costs directly increase the 'urban costs' of large agglomerations.

Figures 17–22 show the effects on pollution sources. An increase in marginal commuting costs increases total commuting costs. This is despite the fact that, because households react by reducing commuting distances, land rents increase and dwelling sizes consequently fall. We also find that manufacturing production falls (since unskilled wages and hence production costs rise to compensate for commuting costs) and agricultural production rises because of the reallocation of unskilled workers. Goods transport costs rise with commuting costs in the core-city and fall in the periphery-city. Interestingly, the combined effect is that total emissions fall with commuting costs (see Fig. 22). The effects of agglomeration

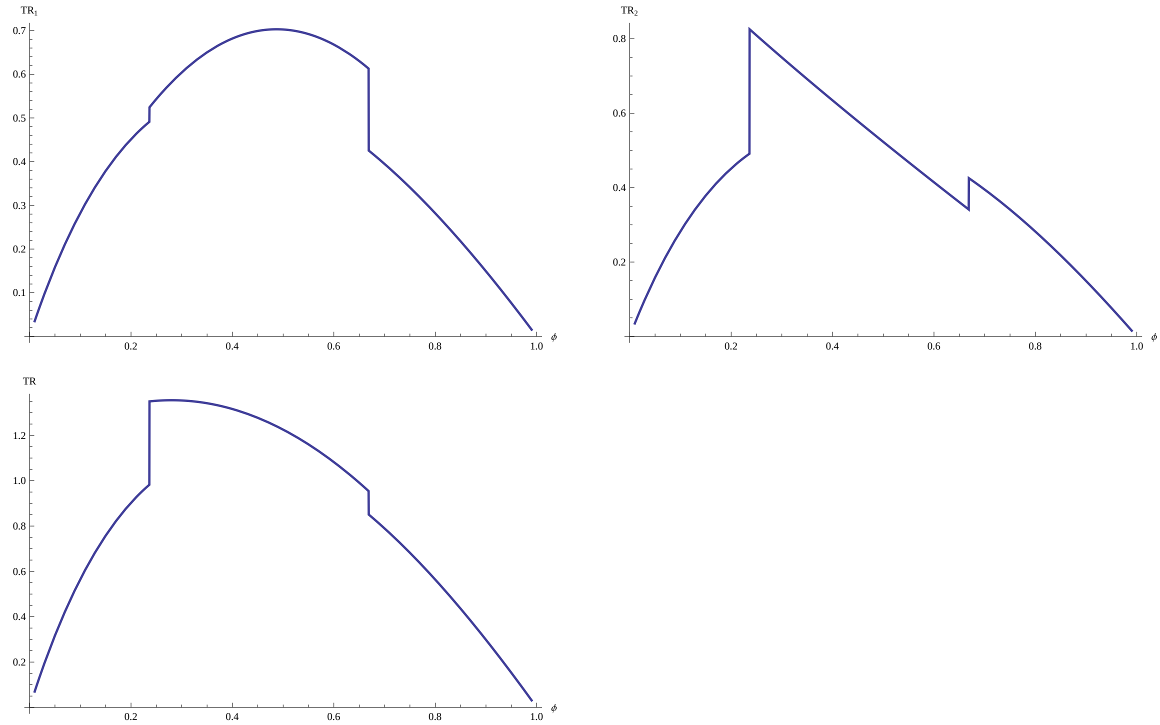

Figure 4: Pollution and trade freeness (transport)

are as described before.

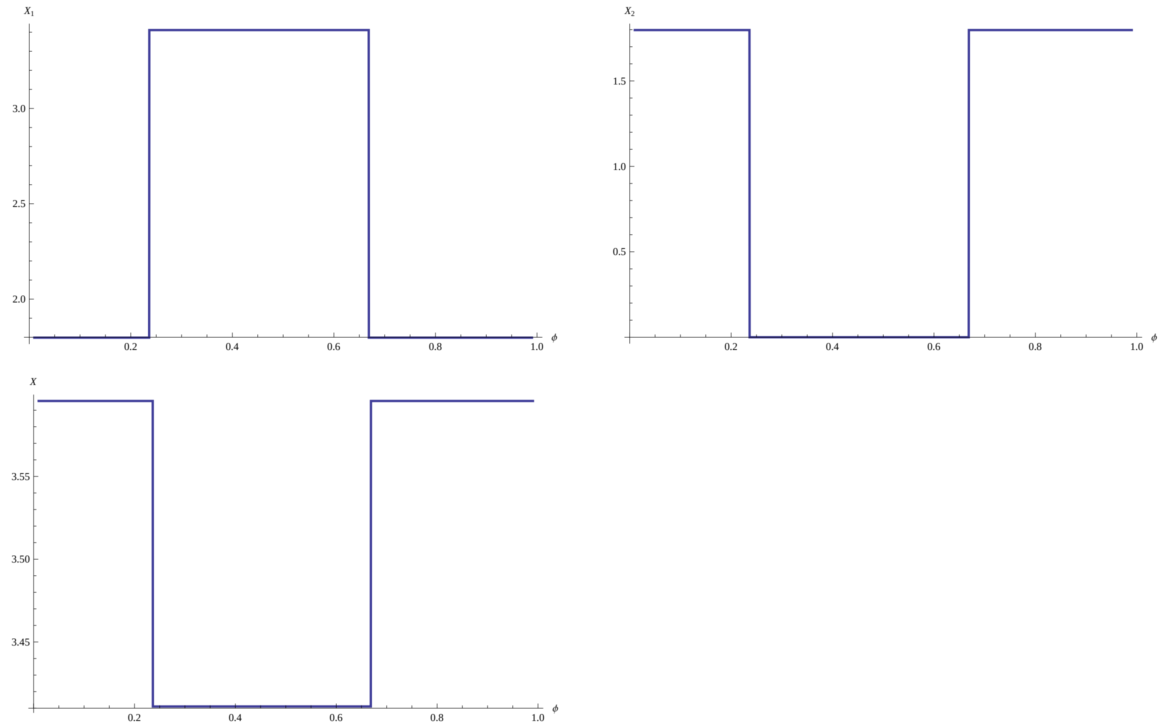

Figure 5: Pollution and trade freeness (manufacturing)

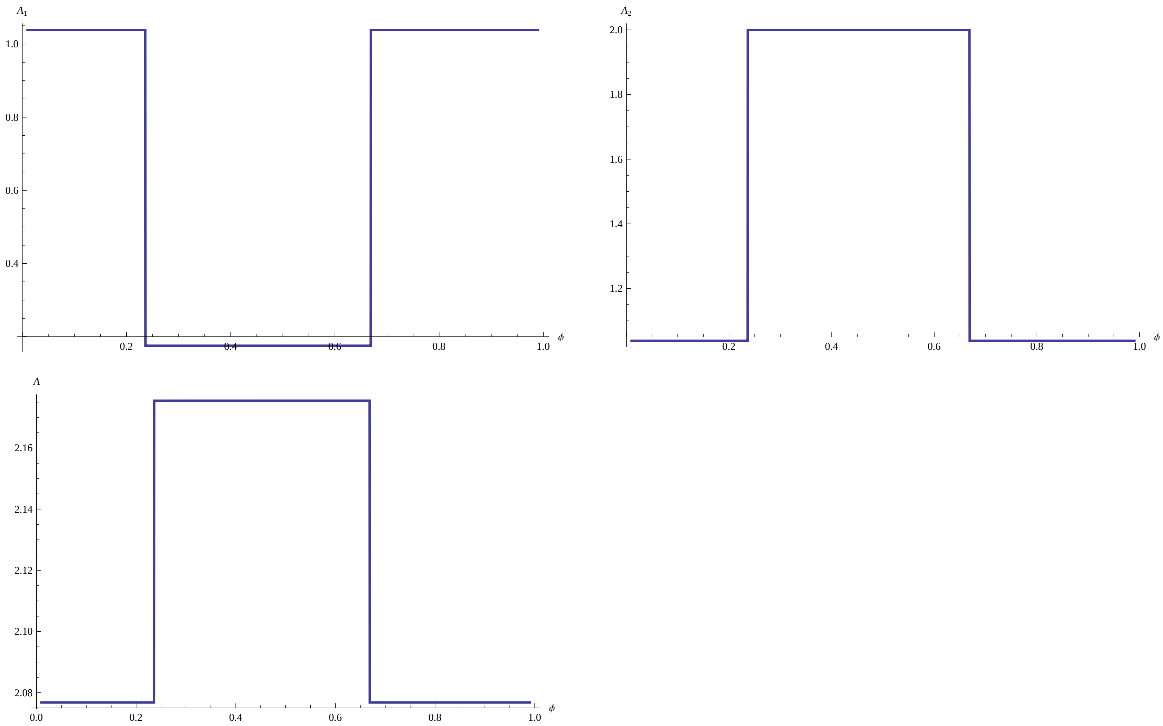

Figure 6: Pollution and trade freeness (agriculture)

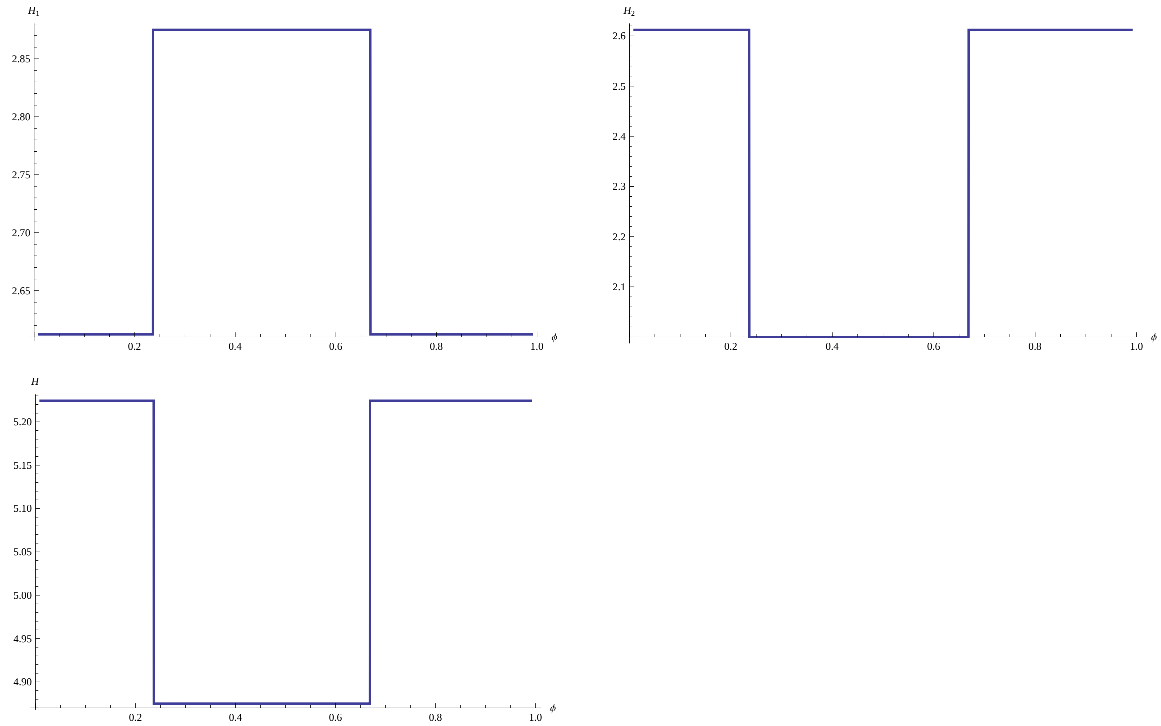

Figure 7: Pollution and trade freeness (housing)

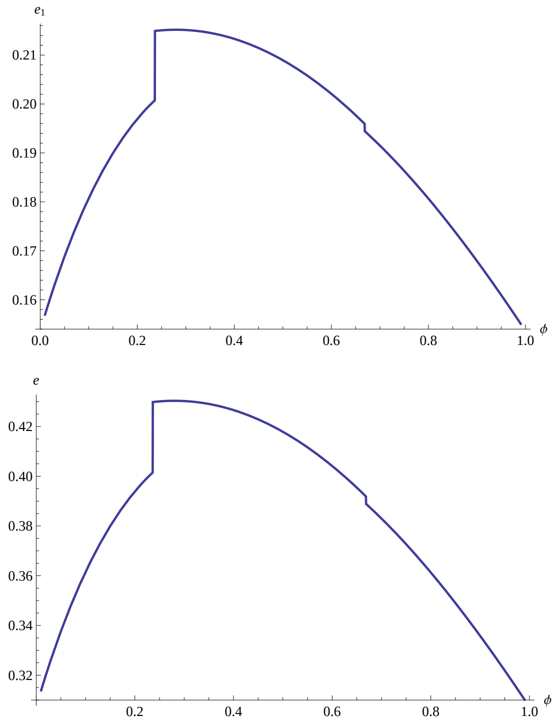

Figure 8: Pollution and trade freeness

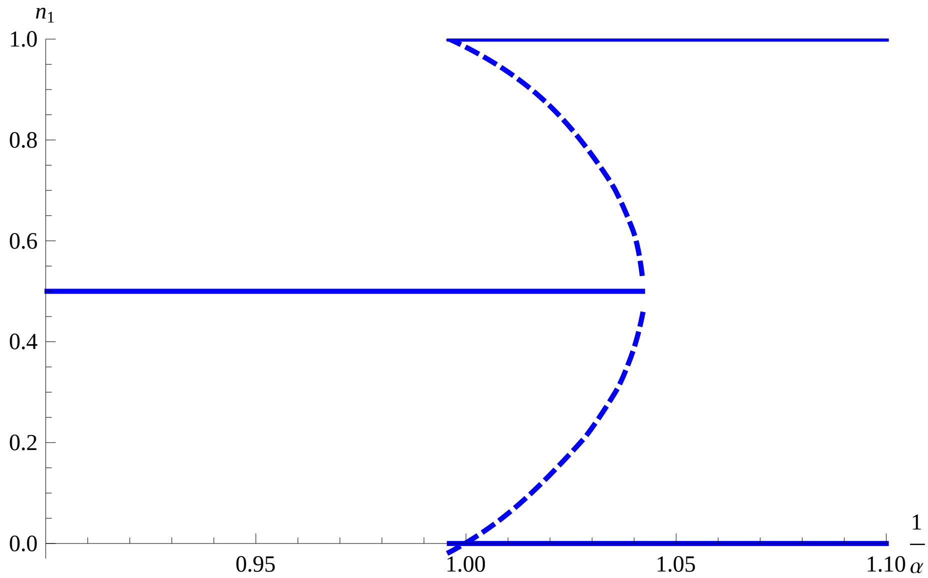

Figure 9: Bifurcation diagram (varying $1/\alpha$)

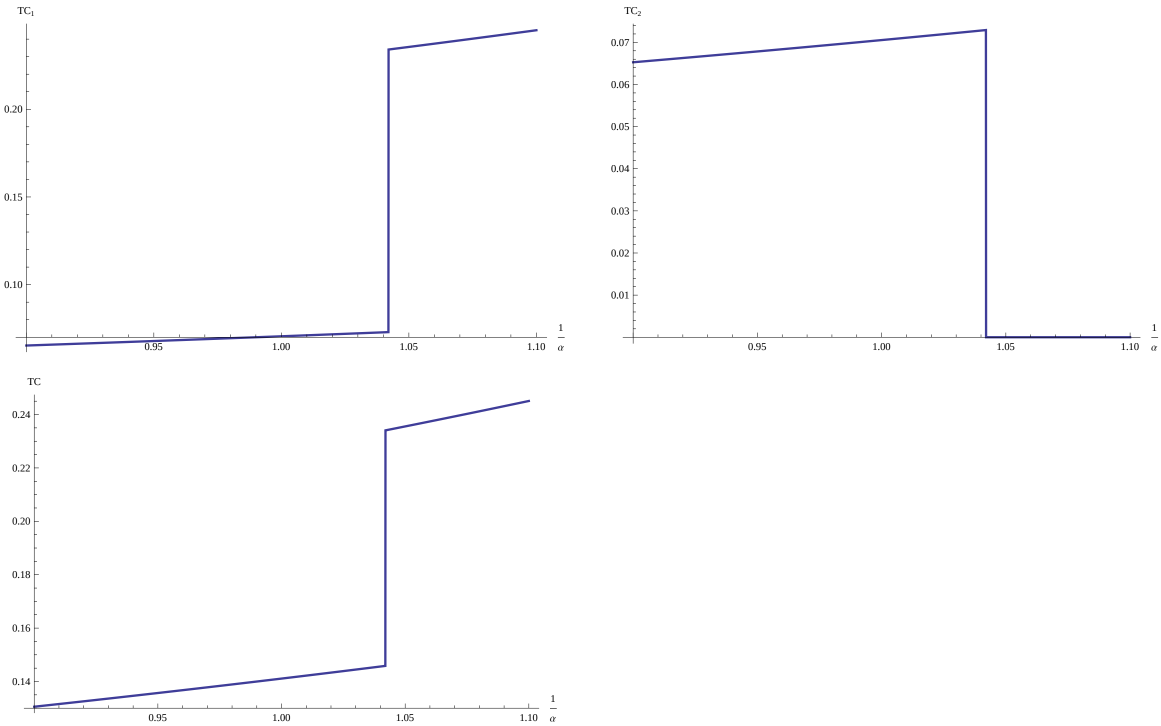

Figure 10: Pollution and income (commuting)

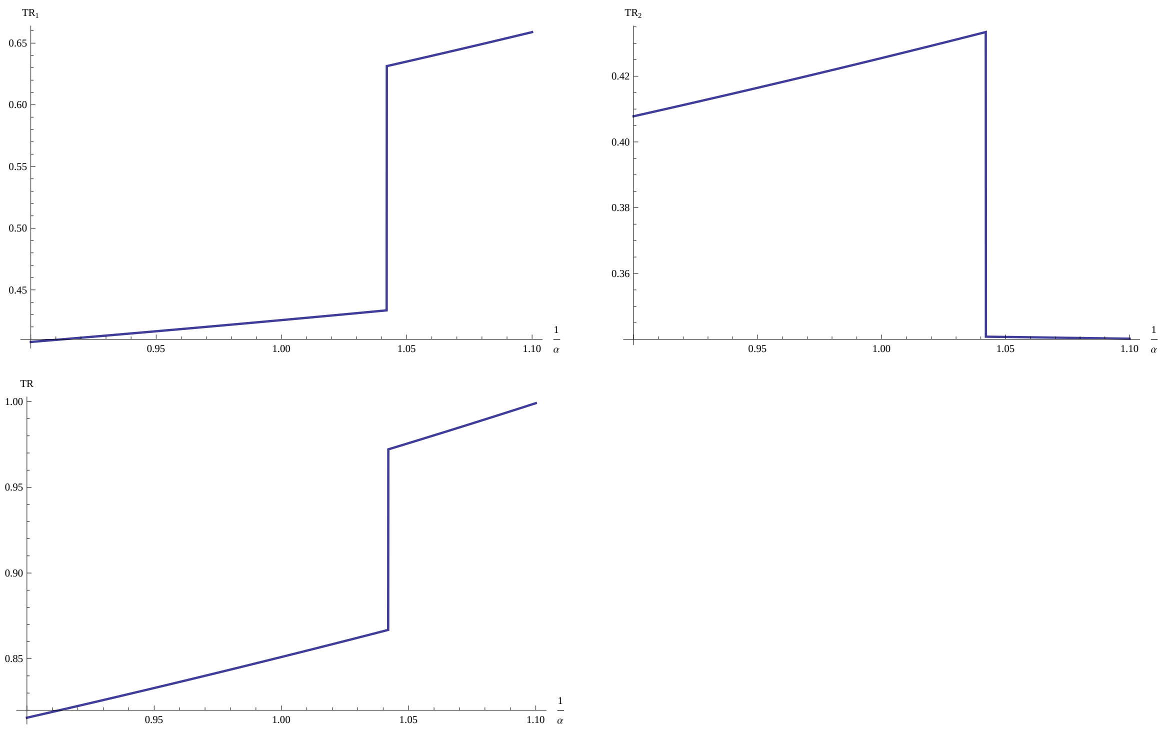

Figure 11: Pollution and income (transport)

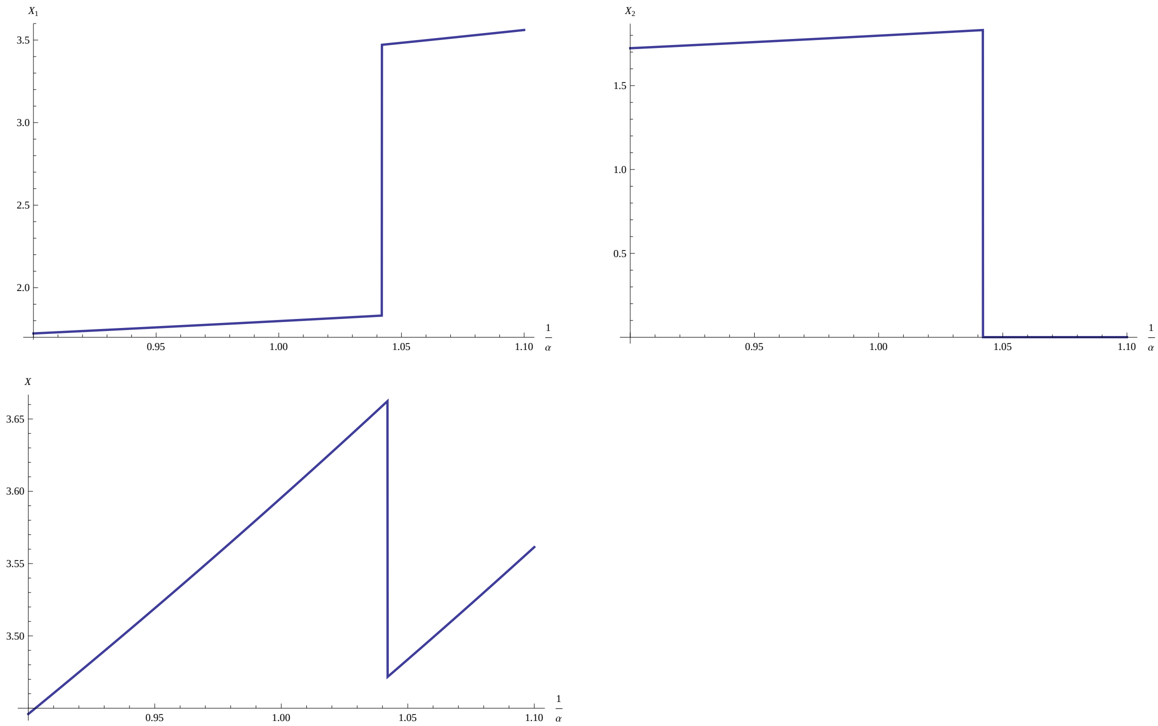

Figure 12: Pollution and income (manufacturing)

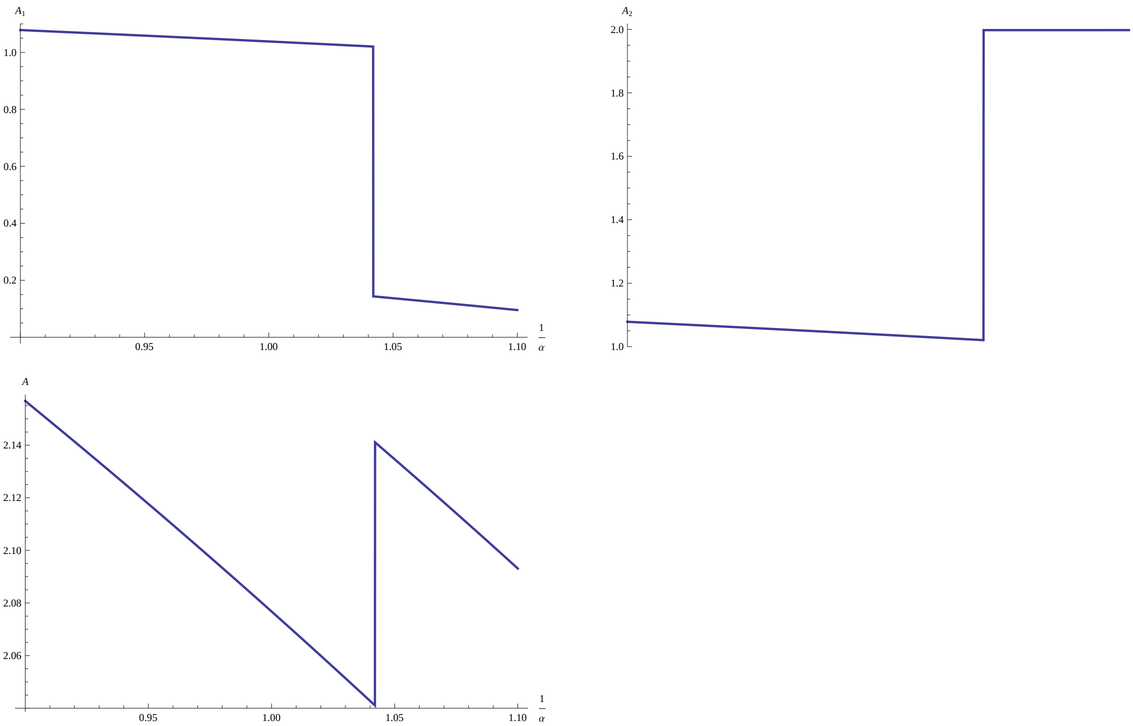

Figure 13: Pollution and income (agriculture)

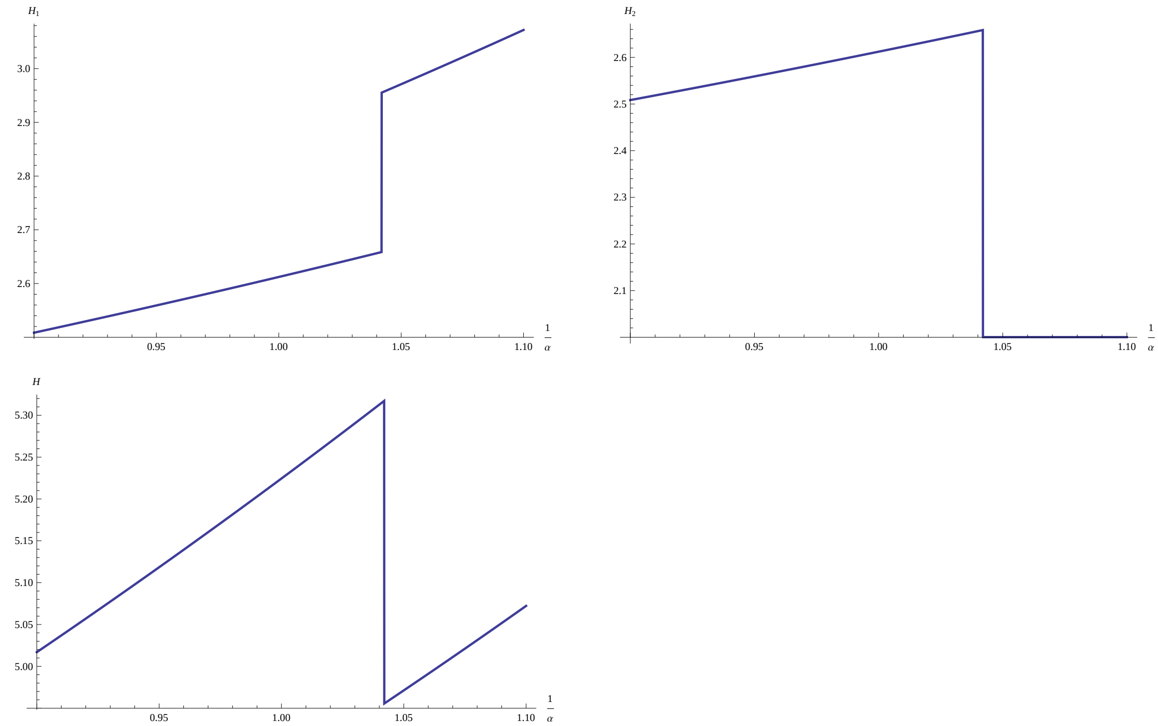

Figure 14: Pollution and income (housing)

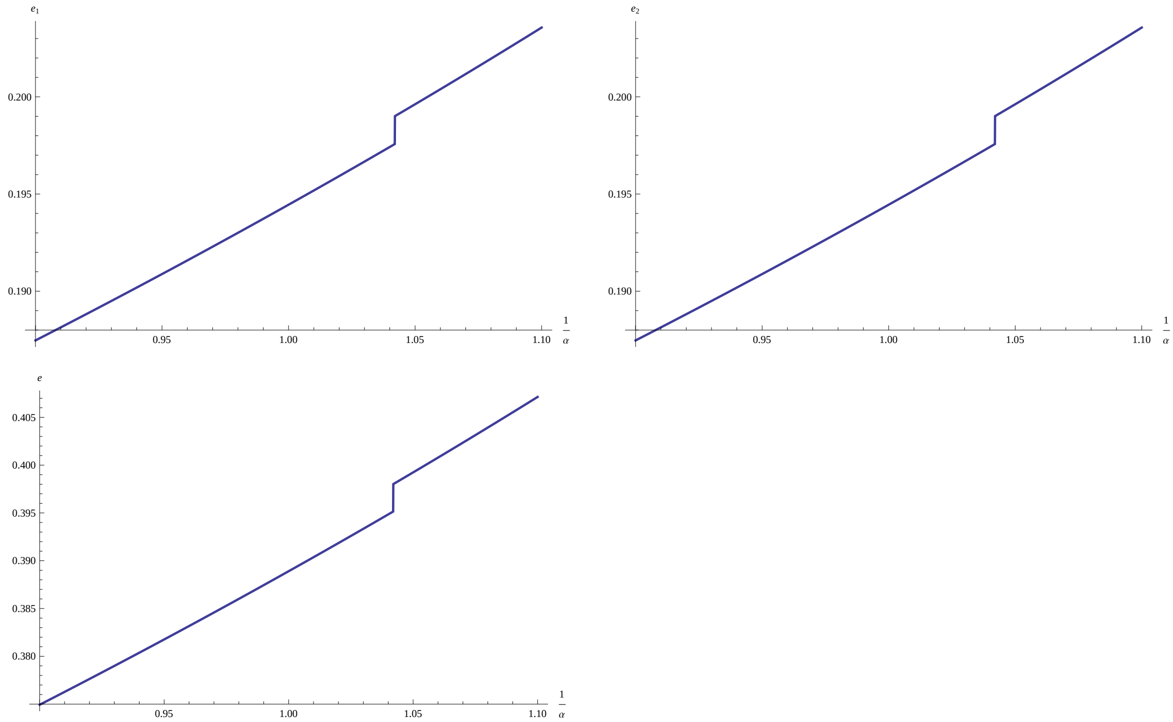

Figure 15: Pollution and income

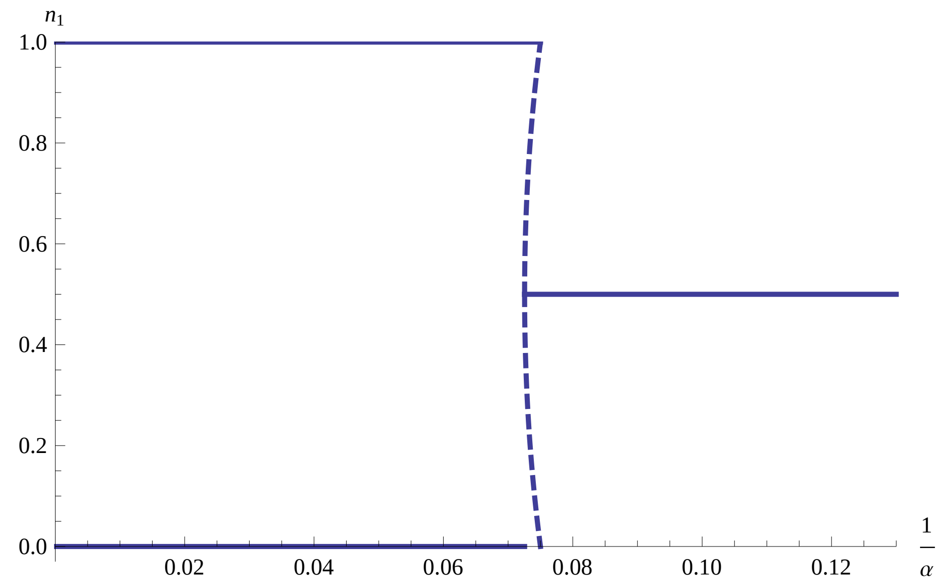

Figure 16: Bifurcation diagram (varying t)

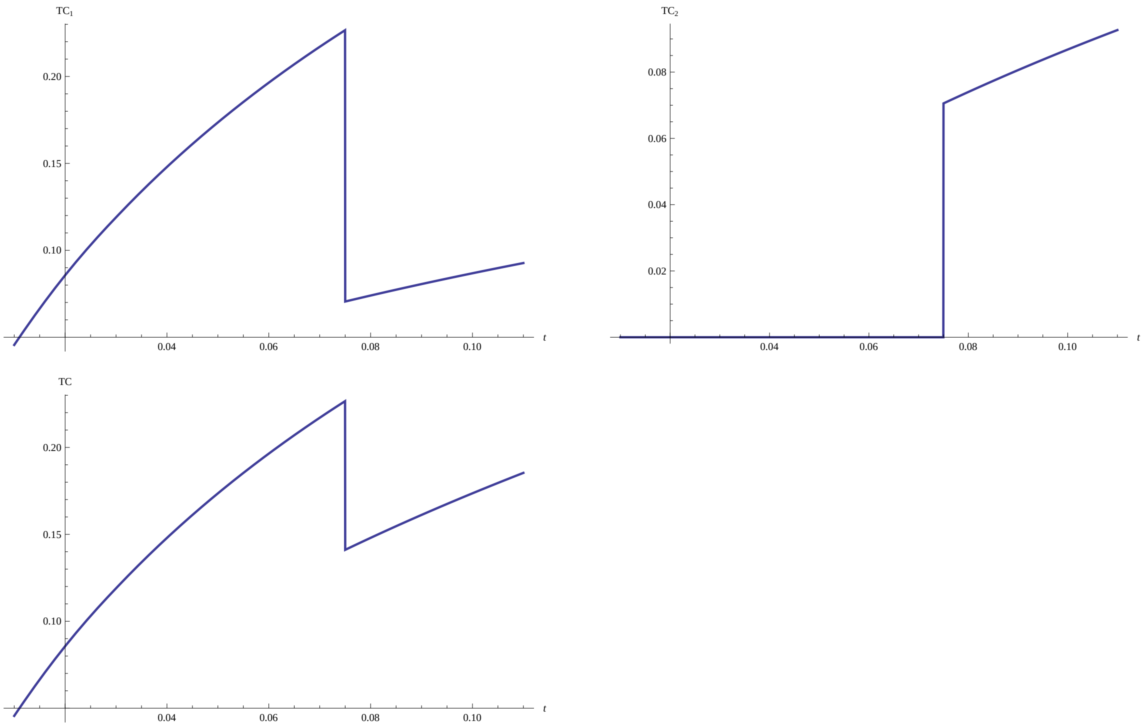

Figure 17: Pollution and commuting costs (commuting)

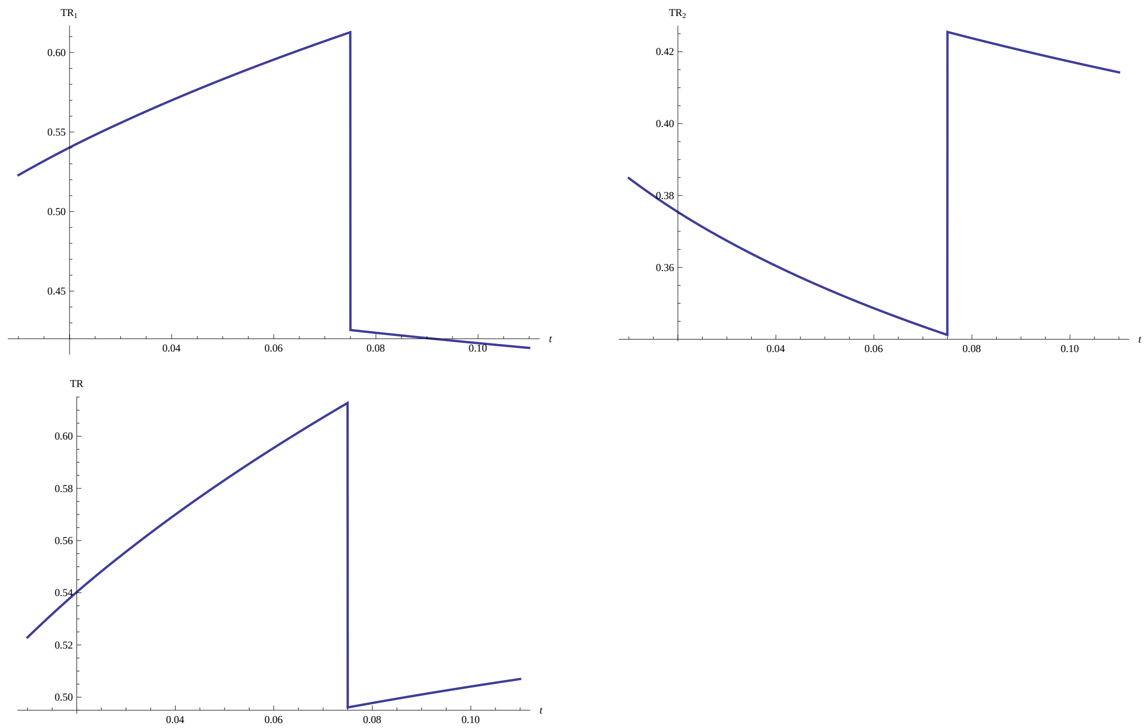

Figure 18: Pollution and commuting costs (transport)

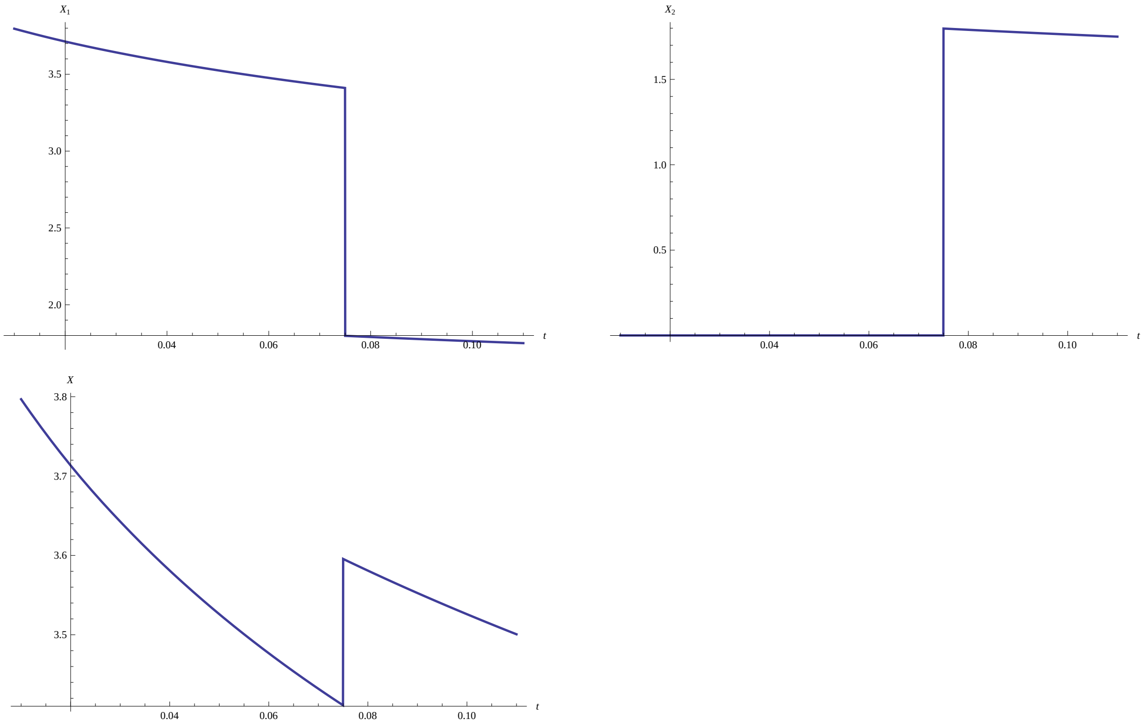

Figure 19: Pollution and commuting costs (manufacturing)

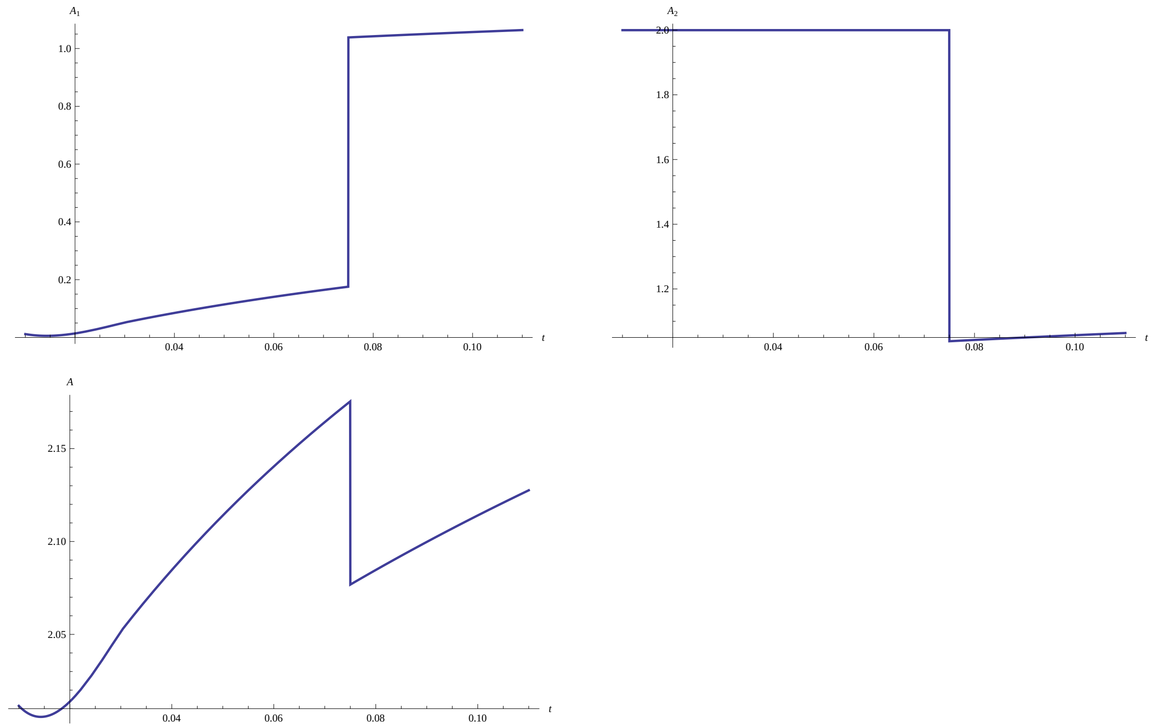

Figure 20: Pollution and commuting costs (agriculture)

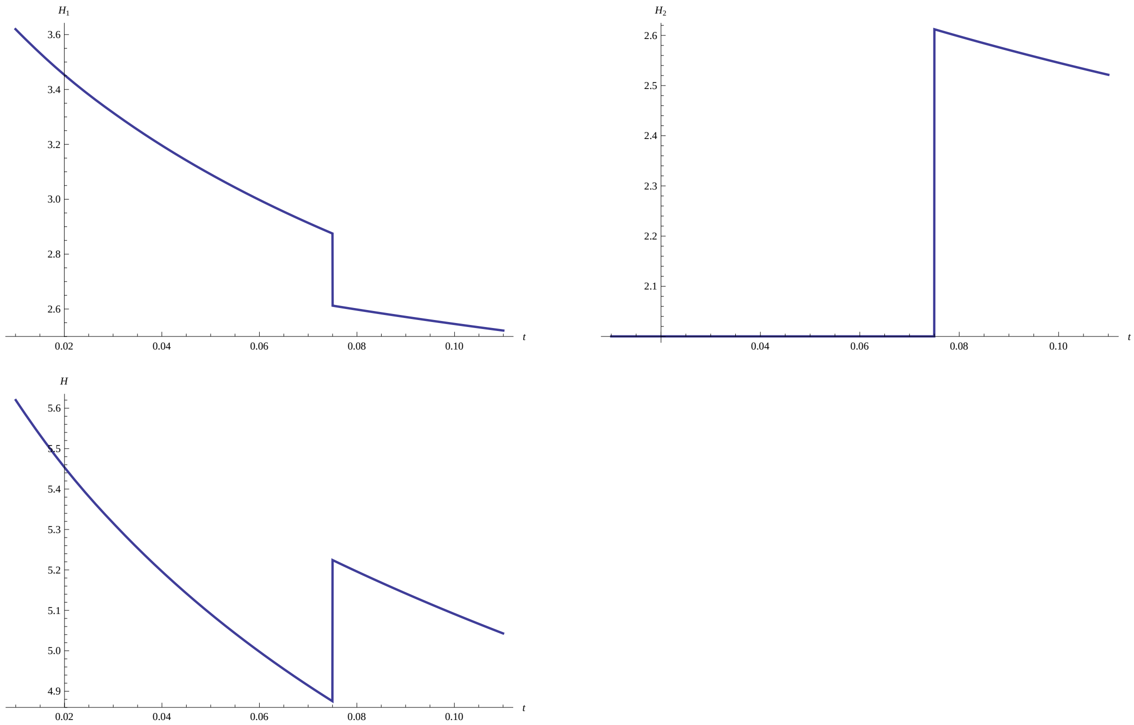

Figure 21: Pollution and commuting costs (housing)

4 Conclusion

This paper sets up a simple theoretical model in order to disentangle how key forces drive the urban system and the concomitant pollution emissions. We have built on Alonsos urban framework and enriched it with market size forces of the new economic geography which obtain under the mobility of labour. Due to our utility specification lot sizes, and, hence, the settlement density in cities are endogenously determined, allowing us to relate our analysis to the recent hypothesis that compact cities are environmental-friendly. Three key parameters shape the space economy and the level and composition of emissions, trade costs, the productivity of skilled workers, and commuting costs. The model is kept deliberately simple in order to study environmental policies and the possibility of a policy-induced Urban Environmental Kuznets Curve in future work.

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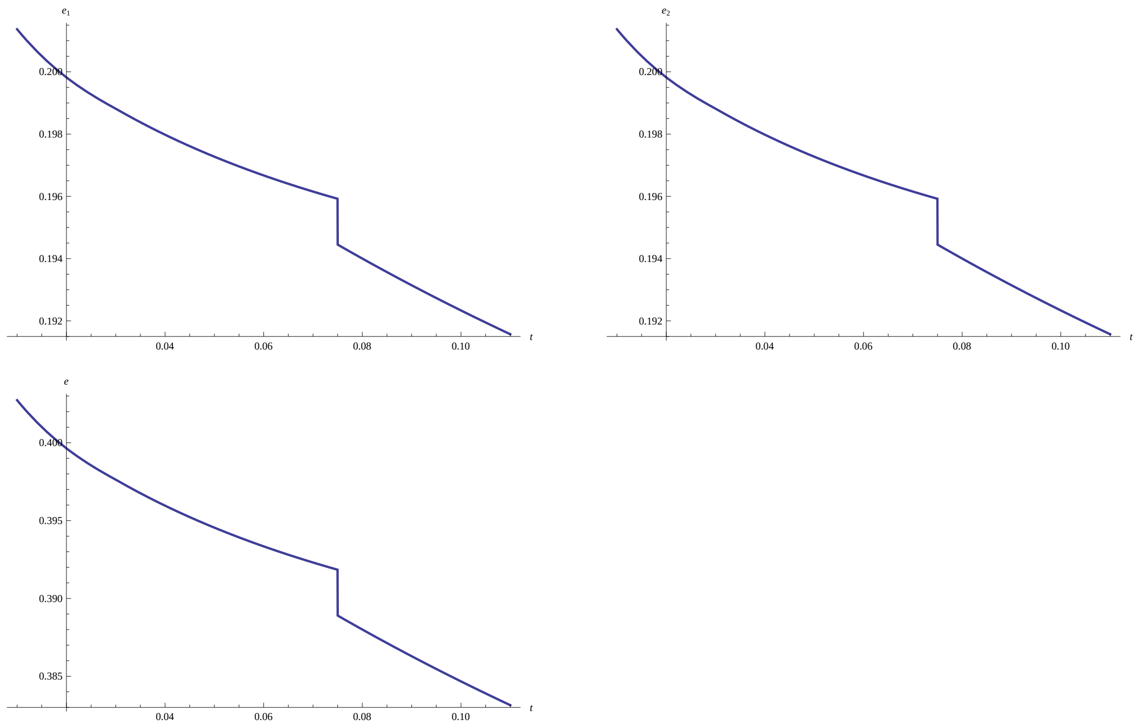

Figure 22: Pollution and commuting costs

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