DISSERTATION

THE IMPACT AND OPTIMIZATION OF THE URBAN INDUSTRIAL MIX

Submitted by

Perry A. Burnett

Department of Economics

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY PERRY A. BURNETT ENTITLED THE IMPACT AND OPTIMIZATION OF THE URBAN INDUSTRIAL MIX BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

Committee on Graduate work

Stephen Davies

David Mushinski

Martin Shields

Advisor – Harvey Cutler

Department Chair – Steven J. Shulman

ABSTRACT OF DISSERTATION

THE IMPACT AND OPTIMIZATION OF THE URBAN INDUSTRIAL MIX

The industrial mix is a relevant issue facing urban economies as the modern economy transitions from an industrial to a post-industrial service-based. The first essay estimates the changes and effects of density that result from relative variations in urban industrial composition. This essay demonstrates that identical increases in aggregate metropolitan employment originating from growth in individual productive sectors result in different average urban density measures. The results suggest that certain urban characteristics are important in determining density's relationship to productivity and that city finances are strained as cities lose manufacturing and gain service sectors.

The second essay estimates the impact of the industrial mix from a land use perspective and evaluates the optimal combination of sectors for a proposed development project using a range of efficiency variables. The results provide a number of insights for policy makers. First, high-wage services yield the largest increase of population and household income whereas retail's modest indirect effects make it attractive to areas with limited available land. Second, sectors have unique land requirements that can be used to derive optimal zoning policies. Third, the results reveal sector growth complements: sectors that interact with each other to increase efficiency measures. Finally, the results demonstrate that if manufacturing is unavailable, export growth in retail or tourism can substitute.

The third essay analyzes the industrial mix in the context of optimal city size. Unlike previous work on optimal city size that use real externalities to derive optimal size, this paper estimates optimal city size with pecuniary externalities that is made possible due to the inefficiency of an unequal distribution of land and capital rent to households inside the city. The essay is able to determine the degree of overpopulation and estimate the shifts of the inverted U due to changes in the industrial mix. The results show that a relative increase in export growth for services leads to a larger city size, whereas total factor productivity growth in manufacturing sector lead to a larger optimal city size.

Perry A. Burnett
Department of Economics
Colorado State University
Fort Collins, CO 80523
Summer 2009

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

1. INTRODUCTION

1.1 INTRODUCTION

The industrial mix is a relevant issue facing urban economies as the modern economy transitions from an industrial to a post-industrial service-based. Key, Pratt and Warner (2007) review the changing industrial structure away from manufacturing toward services and conclude that it is an essential element in regional economic analysis and development. Focusing on the metropolitan area, Desmet and Fafchamps (2005) find that service sector jobs have moved to areas of high aggregate employment such as metropolitan counties and cities, whereas non-service sector jobs, such as manufacturing, have moved away from employment clusters.

With specifics to the industrial composition within cities, Kolko (1999) finds the level of business services and manufacturing employment differs significantly by city size. As city size increases, business services maintain a larger share of employment and that the manufacturing-to-business services employment ratio declines as city size increases.[1] Henderson (1988, 1997) and Black and Henderson (2003) describe the changes to the industrial composition of cities as they differ in size and move up the urban hierarchy. Some of the main differences are in the types of manufacturing and services. Henderson (1997) finds that small and medium cities are more specialized in production with manufacturing sectors having standardized the production process resulting in high physical output per worker. Larger cities have more diverse manufacturing with low output per worker and more R&D activities. The types of services also differ. Small and medium cities are local repair and retail centers or college

[1] Kolko (1999) defines business services by the SIC codes 60-60 (FIRE) and 70-89 (Services). These are services that cater primarily to other businesses, not households. They do not include wholesale, retail or consumer services such as medical, dry cleaning and education, though they do include advertising, consulting and janitorial services.

towns whereas larger cities contain more modern services such as advertising, consulting, the arts and FIRE. Services in larger cities are more export-oriented.

Apart from descriptive differences, the urban industrial mix has effects on regional characteristics such as income inequality and growth measures such as population, employment and employment variability. Bartik (1991) finds that a shift toward high-wage industries has an ambiguous effect on income distribution as it closes the gap for the middle class against the rich, but increases inequality between the middle class and the poor. Cloutier (1997) finds that the industrial mix of a city has a significant impact on income distribution and that the manufacturing and public sectors decrease income inequality whereas high wage services increase inequality. Beeson and DeJong (2001) focus on national trends of population growth from 1840-1990 and found that the industrial mix impacts population growth. They state that counties with larger percents of employment in commerce and manufacturing have had higher population growth rates.[2] Garcia-Mila and McGuire (1993) focus on the industrial mix and long-term growth employment rates and found that it helps to explain the differences in net growth rates of employment as well as variability in employment across the states. They find that states with large concentrations of FIRE, construction and services had unexpectedly high employment growth, while states with larger employment levels in transportation, public utilities and manufacturing has unexpectedly lower growth. They also find that economies with higher service employment tend to experience more variability. They report that many states focus development on manufacturing, but that this may be misguided due to the fact that services are growing at a faster rate than manufacturing

[2] They note that this may be due to the rise of manufacturing during their sample and that counties with larger shares of this industry simply benefited from this.

and states with larger shares of fast-growing industries have had higher growth rates of employment.

Given the changing industrial mix at both the national and urban levels and its effects on regional characteristics, this dissertation extends the research and understanding of the impacts of the industrial mix on the urban environment and begins to analyze its optimization for use in local policy and by urban and regional planners. This objective is accomplished through three essays that implement the use of a computable general equilibrium (CGE) model. The CGE framework is ideally suited for this research as it is able to capture the interdependencies of an urban system under profit and utility maximization and allows for a quantitative evaluation of exogenous changes to the system. It is also independent of the effects of local government policies and assumes no specific spatial structure of the city such as mono or polycentric.

The first essay focuses on the changes to and the fiscal effects of density that result from relative variations in urban industrial composition. Individual productive sectors within the urban industrial mix vary in structure such as land and labor intensity, the composition of employment from low to high wage workers and the distribution of sales to local consumers or exports. All of these characteristics can and do contribute to a sector's effect on density. This essay demonstrates that identical increases in aggregate metropolitan employment originating from growth in individual productive sectors result in different average urban density measures.

The results show that the transition to a post-industrial service economy can explain current trends in density as service sectors support higher urban densities compared to manufacturing sectors. The essay also demonstrates that sector growth under optimality has the ability to spatially expand the city and reduce population density. Regarding the effects of density, the results suggest that certain urban characteristics are important in determining density's relationship to productivity and that city finances are strained as cities lose manufacturing and gain service sectors.

The second essay estimates the impact of the industrial mix on the local environment from a land use perspective and evaluates the optimal combination of sectors for a proposed development project using a range of efficiency variables. The results provide a number of insights for policy makers. First, high-wage services, such as medical, legal, computer, management and engineering, yield the largest increases of population and household income per acre of sector expansion whereas Retail's modest indirect effects make it attractive to areas with limited available land. Second, individual sectors have unique land requirements (or land multipliers) that can be parsed into commercial and residential land to derive optimal zoning policies. Third, the results reveal *sector growth complements*: sectors that interact with each other to increase efficiency measures. Finally, the results demonstrate the importance of traditional manufacturing to medium and small cities; however, if manufacturing is unavailable, export growth in retail or tourism can substitute and increase most efficiency measures.

The third essay analyzes the industrial mix in the context of optimal city size. Urban economic theory hypothesizes an inverted-U relationship of real income per worker against city size with optimal city size occurring at the peak. Unlike previous work on optimal city size that use real externalities to derive optimal size, this paper estimates optimal city size with pecuniary externalities given the inefficiency provided by the unequal distribution of land and capital rent inside the city. Unlike real externalities, that directly affect the resources of a third party, pecuniary, or distributional, externalities operate though changes in relative prices. The essay is able to determine the degree of overpopulation within a single city and estimate the predicated shifts of the inverted U that is due to changes in the industrial mix. The results show that a relative increase in export growth for services leads to a larger city size compared to export growth in manufacturing, whereas total factor productivity growth in manufacturing sector lead to a larger optimal city size than productivity growth in services.

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2. DESCRIPTION OF CGE MODEL AND DATA FOR 2004 MODEL

2.1 DESCRIPTION OF CGE MODEL

The CGE model is a set of simultaneous equations that characterizes the relationships between actors within the local economy and the region/rest of world that allows for a quantitative evaluation of exogenous changes to the system. The local economy is composed of productive sectors, households and the local government (see Figure 2.1 for the structure of the system). The model is a static CGE model following Berck, Golan and Smith's (1996) *Dynamic Revenue Analysis Model* (DRAM) with the base data reflecting the City of Fort Collins, Colorado and the inclusion of equations to model specifics of the city, including commuting behavior and incorporation of land into the production function.

Productive Sectors

The model has 20 productive sectors that maximize profits using intermediate inputs (V_I) in fixed proportions (AD_I) [Equation (4)] and factor demand for land (FD_{LA}), capital (FD_K), and labor (FD_L), with labor disaggregated by wage into low (L_1: less than \$20,000), medium (L_2: \$20,000 to \$50,000) and high wage (L_3: more than \$50,000) workers. Output is sold in perfectly competitive markets under constant returns to scale with mobile factors of production. Equations (2) and (3) model sector output/domestic supply (DS_I) as a Cobb-Douglas production relationship and the subsequent first-order conditions. Equation (1) models the prices seen by productive sectors or value added price (PVA_I). $DELTA_I$ are scale parameters and $ALPHA_{F,I}$ are the relative shares of factors. $TAUQ_{GS,I}$ and $TAUFX_{GF,F,I}$ designate taxes. $R_{F,I}$ and RA_F represent factor wages and rental rates. PD_I and P_I indicate domestic and aggregate prices respectively. The definitions of indices are found at the end of the model description.

$$PVA_I = PD_I - \sum_I AD_I * P_I * (1 - \sum_{GS} TAUQ_{GS,I}) \tag{1}$$

$$DS_I = DELTA_I * \prod_F \left(FD_{F,I}{}^{ALPHA_{FI}} \right) \tag{2}$$

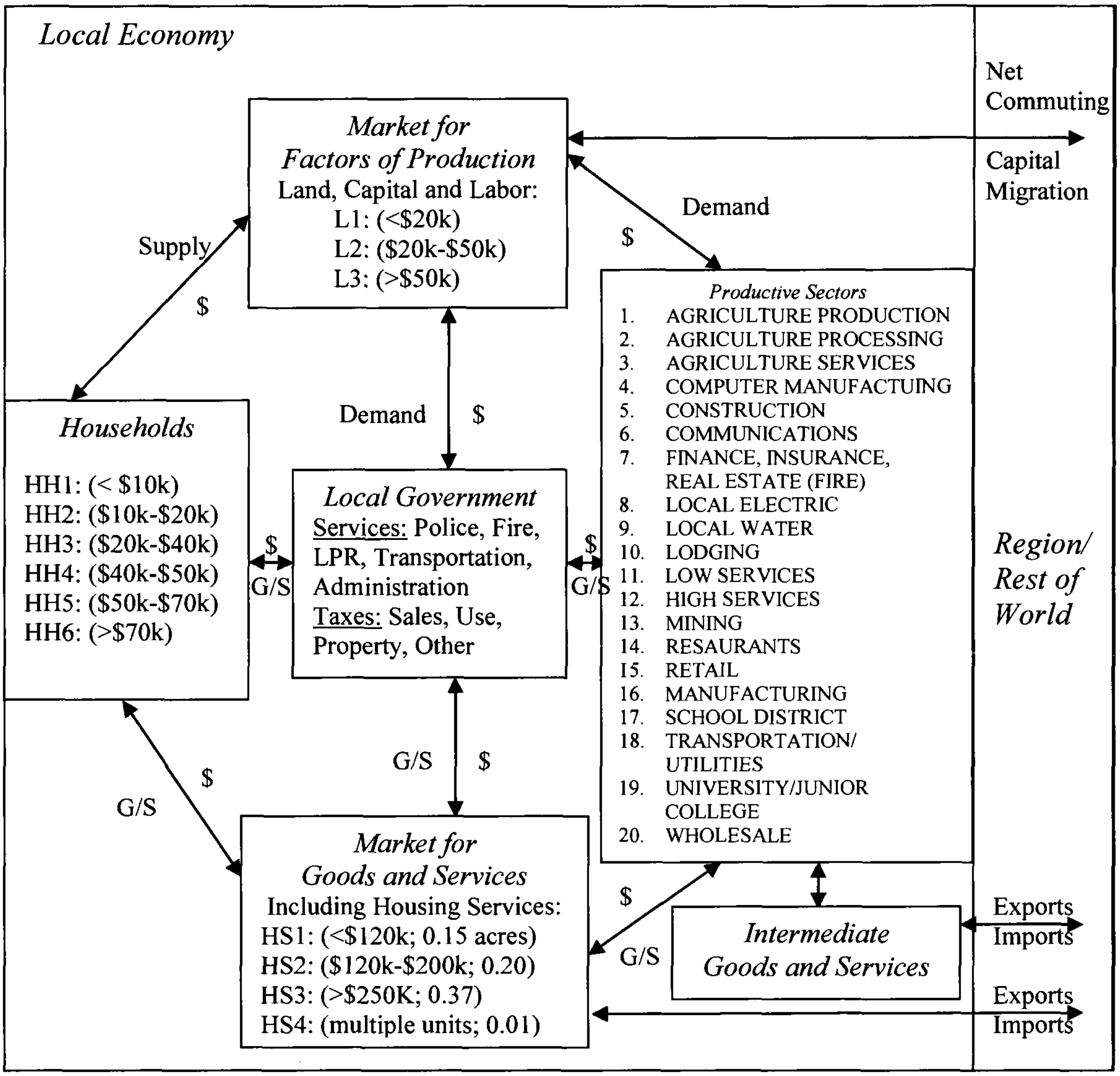
$$R_{F,I} * RA_F * \left(1 + \sum_{GF} TAUFX_{GF,F,I}\right) * FD_{F,I} = PVA_I * DS_I * ALPHA_{F,I} \tag{3}$$

$$V_I = \sum_I AD_I * DS_I \tag{4}$$

Factor Supply

Labor is supplied by working resident households (HW_H), workers commuting into town (CMI_L) and household in-migration (MI_H). Equation (8) models total resident households (HH_H) as a function of the natural rate of population growth ($NRPG_H$) and the net migration of households. Net migration is a function of disposable household income (YD_H) divided by the domestic price level (CPI_H) and the relative number of non-working households (HN_H) to total households. $EYATD_H$ and $ETAU_H$ are migration elasticities. Equation (9) determines the portion of local working households (HW_H) as a function of domestic real wages, external wages ($EXWGE_L$) and transfer payments ($TP_{H,G}$). $JOBCOR_{H,L}$ translates households into workers. $ETARA_H$ and $ETAPT_H$ are labor supply elasticities. The model allows for unemployed or non-working households (HN_H) in equation (5) as the difference between the number of total of households and number of working households. Commuting in (CMI_L) is modeled in Equations (6) as a function of relative domestic wages and external wages ($EXWGE_L$).

Figure 2.1: Model Structure



CMO_L is commuting out is modeled similar in equation (7). $ECOMO_L$ and $ECOMI_L$ are commuting elasticities. Variables followed by a zero (0) are base values.

$$HN_H = HH_H - HW_H \tag{5}$$

$$CMO_L = CMO0_L * \left(\frac{EXWGE_L}{RA_L}\right)^{ECOMO_L} \tag{6}$$

$$CMI_L = CMIO0_L * \left(\frac{RA_L}{EXWGE_L}\right)^{ECOMI_L} \tag{7}$$

$$HH_H = HH0_H * NRPG_H + MI0_H * \left(\frac{\left(\frac{YD_H / HH_H}{YD0_H / HH0_H}\right)}{\left(\frac{CPI_H}{CPI0_H}\right)}\right)^{ETAYD_H} * \left(\frac{\left(\frac{HN_H}{HH_H}\right)}{\left(\frac{HN0_H}{HH0_H}\right)}\right)^{ETAU_H}$$

$$- MO0_H * \left(\frac{\left(\frac{YD_H / HH_H}{YD0_H / HH0_H}\right)}{\left(\frac{CPI_H}{CPI0_H}\right)}\right)^{ETAYD_H} * \left(\frac{\left(\frac{HN_H}{HH_H}\right)}{\left(\frac{HN0_H}{HH0_H}\right)}\right)^{ETAU_H} \tag{8}$$

$$\frac{HW_H}{HH_H} = \frac{HW0_H}{HH0_H} * \left(\begin{array}{l} \left(\frac{\left(\sum_L \left(\frac{RA_L}{RA0_L}\right) / 3\right)}{\left(\frac{CPI_H}{CPI0_H}\right)}\right) * \left(\frac{\sum_{L,Z} FD_{Z,L}}{\sum HW_H * \sum_H JOBCOR_{H,L}} + \sum_L CMI_L\right) \\ + \left(\sum_L \left(\frac{EXWGE_L}{RA_L}\right) / 3\right) * \left(\frac{\sum_L CMO_L}{\sum HW_H * \sum_H JOBCOR_{H,L}} + \sum_L CMI_L\right) \end{array}\right)^{ETARA_H}$$

$$* \left(\frac{\sum_G \left(\frac{TP_{H,G}}{CPI_H}\right)}{\sum \left(\frac{TP_{H,G}}{CPI0_H}\right)}\right)^{ETAPT_H} \tag{9}$$

Capital supply is modeled as a two-stage process. Gross investment decisions or new capital ($N_{K,I}$) is a function of its base value and relative rate of return in equation (10). Domestic supply is also a factor. $ETAIX_{K,I}$ is an investment elasticity. New capital is then distributed to sectors (CN_I) by the capital investment matrix ($A_{I,IG}$) in equation (11). Capital stock ($KS_{K,IG}$) is a function of its base value, the rate of depreciation (DEPR) and new capital in equation (12). Land supply ($LS_{LA,I}$) is a function of its base value and relative rate of return in equation (13). Equations (14)-(16) calculate factor incomes (Y) as functions of their respective factor demand and rental rates.

$$N_{K,I} = N0_{K,I} * \left(\frac{R_{K,I}}{R0_{K,I}} \right)^{ETAIX_{K,I}} * \left(\frac{DS_I}{DS0_I} \right)^{ETAIX_{K,I}} \tag{10}$$

$$P_I * \left(1 + \sum_{GS} TAUQ_{GS,I}\right) * CN_I = \sum_{IG} \left(A_{I,IG} * \left(\sum_K N_{K,IG}\right)\right) \tag{11}$$

$$KS_{K,IG} = KS0_{K,IG} * (1 - DEPR) + N_{K,IG} \tag{12}$$

$$LAS_{LA,I} = LAS_{LA,I} * \left(\frac{R_{LA,I}}{R0_{LA,I}} \right)^{ETAL_{LA,I}} \tag{13}$$

$$Y_L = \sum_{IG} R_{L,IG} * RA_L * FD_{L,IG} \tag{14}$$

$$Y_K = \sum_{IG} R_{K,IG} * RA_K * FD_{K,IG} \tag{15}$$

$$Y_{LA} = \sum_{IG} R_{LA,IG} * RA_{LA} * FD_{LA,IG} \tag{16}$$

Households

Households are divided into six income groups (HH1 to HH6) and consume four types of housing services (HS1 to HS4) (see Figure 1 for description). Consumption demand ($CH_{I,H}$) is derived from households maximizing utility under a Cobb-Douglas specification in Equation (20). $BETA_{I,H}$ and $LAMBA_{I,H}$ are income and price elasticities respectively. Equation (17) describes the price level faced by each household group (CPI_H). Equation (18) depicts gross household income as derived from labor (Y_L), commuting income ($CMIWAGE_L$ * CMI_L), land (Y_{LA}) and capital (Y_K) payments with disposable income (YD_H), in equation (19), obtained through netting out personal income ($PIT_{GI,H}$) and other taxes ($TAUH_{G,H}$) and adding retirement income ($PRIVET_H$) and transfer payments. While resident households receive income from land and capital, there is significant foreign ownership, in part from national chains, resulting in land and capital income leaving the local economy ($LNFOR_{LA}$ and $KPFOR_K$). Households allocate disposable income to the consumption of goods and services, saving/investment and net transfers outside the local economy. Equation (21) depicts saving (S_H) as the residual from disposable income after utility maximizing consumption and taxes.

$$CPI_H = \frac{\sum_I P_I \left(1 + \sum_{GS} TAUQ_{GS,I}\right) * CH_{I,H}}{\sum_I P0_I \left(1 + \sum_{GS} TAUQ_{GS,I}\right) * CH_{I,H}} \tag{17}$$

$$Y_H = \left(\sum_L \left(\frac{A_{L,H} * HW_H}{\sum_H \left(A_{L,H} * HW_H \right)} \right) * \left(Y_L + \left(CMIWAGE_L * CMI_L \right) \right) * \left(1 - \sum_G TAUFL_{G,L} \right) \right)$$

$$+ A_H COMMO * CMOWAGE_L * CMO_L$$

$$+ \left(\sum_{LA} \left(\frac{A_{LA,H} * HW_H}{\sum_H \left(A_{LA,H} * HW_H \right)} \right) * \left(Y_{LA} + LNFOR_{LA} \right) * \left(1 - \sum_G TAUFL_{G,LA} \right) \right) \tag{18}$$

$$+ \left(\sum_K \left(\frac{A_{K,H} * HW_H}{\sum_H \left(A_{K,H} * HW_H \right)} \right) * \left(Y_K + KPFOR_K \right) * \left(1 - \sum_G TAUFL_{G,K} \right) \right)$$

$$Y_D = Y_H + (PRIVRET_H * HH_H) + \sum_G (TP_{H,G} * HH_H)$$

$$- \sum_{GI} (PIT_{GI,H} * HH_H) - \sum_G (TAUH_{G,H} * HH_H) \tag{19}$$

$$CH_{I,H} = CH0_{I,H} * \left(\frac{YD_H / YD0_H}{CPI_H / CPI0_H} \right)^{BETA_{I,H}} * \prod_I \left(\frac{P_I * \left(1 + \sum TAUQ_{Gs,I} \right)}{P0_I * \left(1 + \sum TAUQ_{Gs,I} \right)} \right)^{LAMBDA_I} \tag{20}$$

$$S_H = YD_H - \sum_I P_I * \left(1 + \sum_{GS} TAUQ_{GS,I} \right) * CH_{I,H} \tag{21}$$

Trade Relations

Regions trade with the external economy resulting in the opportunity to export local goods and in competition from imported goods. Exports (CX_I) are a function of the base level and the relative change in domestic versus external prices ($PW0_I$) in equation (22). Imports (M_I) are modeled in a similar fashion in Equations (23). Equation (24) depicts the level of imports as the residual of domestic supply's share (D_I) of domestic demand (DD_I). Aggregate prices are portrayed in Equation (25) as a function of domestic and external prices. Net capital investment (NKI) is essentially modeled as an unconstrained variable in equation (26) given that the nature of Fort Collins is a small, open economy and savings can enter the economy from external sources through branch banking. $ETAE_I$ and $ETAD_I$ are trade elasticities.

$$CX_I = CX0_I * \left(\frac{PD_I}{PW0_I / \left(1 + \sum_{GK} TAUQ_{GK,I}\right)} \right)^{ETAE_I} \quad (22)$$

$$D_I = D0_I * \left(\frac{PD_I}{PWM0_I / \left(1 + \sum_{GK} TAUQ_{GK,I}\right)} \right)^{ETAD_I} \quad (23)$$

$$M_I = (1 - D_I) * DD_I \quad (24)$$

$$P_I = (D_I * PD_I) + \left((1 - D_I) * \left(PWM0_I * \left(1 + \sum_{GK} TAUQ_{GK,I}\right)\right)\right) \quad (25)$$

$$\begin{aligned} NKI = {} & \sum_I (M_I * PWM0_I) - \sum_I (CX_I * PD_I) - \sum_H (PRIVRET_H * HH_H) \\ & - \sum_{LA} LNFOR_{LA} - \sum_K KPFOR_K - \sum_G GVFOR_G \\ & - \sum_L (CMOWAGE_L * CMO_L) - \sum_L (CMIWAGE_L * CMI_L) \end{aligned} \quad (26)$$

Local Government

Local government revenue consists of an assortment of taxes including sales ($TAUC_{GX,I}$), use ($TAUM_{GX,I}$), and property ($TAUFH_{GX}$) taxes along with federal government transfers (IGT_{GX}) in Equation (27). This revenue is used in five local government sectors (Police, Fire, Transportation, Administration, and Library, Parks and Recreation (LPR)). These sectors demand goods and services ($CG_{I,GN}$) from the productive sector and hire workers from households in Equations (28) and (29). They are not modeled as profit maximizing firms; however, they must maintain a balanced budget. The results of the paper will naturally be altered in accordance with policy decisions undertaken by the local government.

$$
\begin{aligned}
Y_{GX} &= \sum_{I}\left(TAUV_{GX,I} * V_{I} * P_{I}\right) + \sum_{I}\left(TAUM_{GX,I} * M_{I} * PWM0_{I}\right) \\
&+ \sum_{H,I}\left(TAUC_{GX,I} * CH_{I,H} * P_{I}\right) + \sum_{I}\left(TAUN_{GX,I} * CN_{I} * P_{I}\right) + \sum_{GN,I}\left(TAUG_{GX,I} * CG_{I} * P_{I}\right) \\
&+ \sum_{F,I}\left(TAUF_{GX,F,I} * RA_{F} * R_{F,I} * FD_{F,I}\right) + \sum_{F,GN}\left(TAUFX_{GX,F,GN} * RA_{F} * R_{F,I} * FD_{F,I}\right) \\
&+ \sum_{L}\left(TAUFH_{GX,L} * \left(Y_{L} + CMIWAGE_{L} * CMI_{L}\right)\right) + \sum_{K}\left(TAUFH_{GX,K} * Y_{K}\right) \\
&+ \sum_{LA}\left(TAUFH_{LA} * Y_{LA}\right) + \sum_{H}\left(PIT_{GX,H} * HH_{H}\right) + \sum_{H}\left(TAUH_{H} * HH_{H}\right) + \sum_{GX}\left(IGT_{GX}\right)
\end{aligned} \tag{27}
$$

$$
P_{I} * \left(1 + \sum_{GS} TAUG_{GS,I}\right) * CG_{I,GN} = AG_{I,GN} * \left(Y_{GN} + GVFOR_{GN}\right) \tag{28}
$$

$$
FD_{F,GN} * R_{F,GN} * RA_{F} * \left(1 + \sum_{GF} TAUFX_{GF,F,GN}\right) = AG_{F,GN} * \left(Y_{GN} + GVFOR_{GN}\right) \tag{29}
$$

Model Closure

The model produces a medium-run equilibrium which occurs after all intermediate effects have occurred estimated to be completed in 2 to 4 years. Equilibrium is achieved under a number of market closure equations. Equation (30) closes the local labor market by setting labor supply equal to labor demand. Equations (31) and (32) do the same with the capital and land markets respectively. Domestic demand is the sum of intermediate inputs, household and government consumption and sector investment in equation (33). The goods and services market closes in equation (34) by setting domestic supply equal to domestic demand and net exports.

$$\sum_H \left(HW_H * JOBCOR_{H,L} \right) + CMI_L = \sum_Z FD_{L,Z} + CMO_L \tag{30}$$

$$KS_{K,IG} = FD_{K,IG} \tag{31}$$

$$LAS_{LA,IG} = FD_{LA,IG} \tag{32}$$

$$DD_I = V_I + \sum_H CN_{I,H} + \sum_G CG_{I,G} + CN_I \tag{33}$$

$$DS_I = DD_I + CX_I - M_I \tag{34}$$

Indices:

I = Productive Sectors	IG = Productive Sectors and Local Government Services
L = Labor Groups	F = Factors of Production (Labor, Land, Capital)
LA = Land Categories	K = Capital Categories
H = Household Groups	G = Local Government Services
GN, GS, GX = Different Tax Jurisdictions	

2.2 DESCRIPTION OF DATA FOR 2004 MODEL

The description of the method and organization of the data described in this section applies to the 2004 version of the CGE model and will describe employment data, land and capital data, and local government data.

Employment Data

Employment data is gathered from two sources: Quarterly Census of Employment and Wages (QCEW) formally ES-202 and Unemployment Insurance (UI) data. QCEW data is derived from quarterly tax report submitted to the Colorado Department of Labor under unemployment insurance (UI) laws. This data provides on the number of employees per month of the quarter and total wage bill of the quarter. UI data is worker-specific data for wages earned per quarter. This is derived from each worker's individual UI number. For our model, this data was acquired through Colorado's Department of Labor. The Labor Department combined both sources of data placing individual workers into their respective firms. The data are quarterly for the years 2001 to 2004.

The data from the Labor Department consists of 117 categories for each firm. This includes the firm's legal and trade names along with their SIC and NAICS codes. The data provide up to three different addresses for each firm: UI, PL, and MO. The UI address is the location of the firm's home office. The PL address is the firm's physical location, and the MO is the last know mailing address by the Labor Department. The PL address is of primary interest. The firms for the cities of Fort Collins, Loveland, Estes Park and Other Larimer County were determined by the ZIP code of the PL address. There are a number of firms that do not provide a PL ZIP code. For these firms, the UI ZIP codes were used for firm location.

To illustrate the difference between the addresses take Blockbuster Video in Fort Collins. There are five Blockbuster Videos in Fort Collins in the third quarter of 2004. Blockbuster Videos are owned by Blockbuster Entertainment Corporation which home office is located in McKinney, Texas; therefore, the UI address for all five Blockbuster Videos is the same at McKinney, Texas. The physical location or PL address for each Blockbuster is different with a specific address in Fort Collins, Colorado.

The employment and wage section of the data is located in two sections. The first section comes from QCEW data and identifies total number of workers for each month of that quarter. For example in the third quarter of 2004, Fort Collins Nursery had 28 employees for July, 19 for August and 19 for September. This section also gives the total wage bill for that quarter. The second section of the wage bill comes from UI data. This section breaks the quarterly wages into 45 subsections that start with wages earned in that quarter of $625 and less and increase incrementally by $625 to the final subsection of over $27,500. This quarterly wage is equivalent to an annual wage of over $110,000. When possible, the UI data is matched with the QCEW firm and a distribution of workers in each category is determined as each worker is placed in one of the 45 wage subsections. For example, Karate West in Fort Collins owned by Championship Karate Inc. employed five people in the third quarter of 2004. Three of the workers earned less than $625 in that quarter. One earned between $4,375 and $5,000 and the last made between $5,000 and $5,265 in that quarter. This distribution is not available for all firms. Firms with multiple locations across the state, such as regional or national chains, do not have these wage distributions as workers in these firms are aggregated under one account.

Turning to technical methods, firms are organized into Microsoft Excel spreadsheets by PL ZIP codes for the areas of Fort Collins, Loveland, Estes Park and Other Larimer County. For firms that do not provide PL ZIP codes, the UI ZIP code was used for firm location. The method to organize blank PL ZIP codes into their respective areas was to utilize the programming available in Microsoft Excel's Visual Basic language. After this organization was preformed, the firms without wage distributions were separated from those that have these distributions.

Employment Data Aggregation

The next sections describe the process and techniques of sector aggregation for employment. The process of sector aggregation follows the aggregation method of the 1996 Fort Collins CGE model. The former model used SIC codes to aggregate sectors. The chosen sectors with appropriate SIC codes and a short description of each code are presented in Table 2.1. There are 21 sectors organized by SIC codes. An issue that will be dealt with later is the SIC code 9999: Non-Classifiable Establishments, which is listed under the Government sector, but is composed of various productive sectors.

The technical methods to organize the firm data into these aggregated sectors follow. The sectors with wage distributions are dealt with first. This data includes the SIC code, the UI ZIP code and the wage distribution. After this data is put into a more workable form, the firm's workers are aggregated first into SIC codes to present one wage distribution per SIC codeThe next step is to aggregate the individual SIC codes into their respective 21 final aggregated sectors.

At this point, the firms with wage distributions have been aggregated into final sectors. The firms to organize next are the firms with blank wage distributions. Recall that there were two listing for employment and wage data: the quarterly data provided by QCEW and the UI wage distribution data. The firms without UI wage distribution data will use QCEW quarterly employment data. This employment data for firms without wage distributions will be distributed into wage categories by the wage ratios derived from the firms with wage distributions.

The final employment aggregation issue to deal with is the firms with SIC codes of 9999: Non-Classifiable Establishments. While classified as Government sector firms, these firms are composed of a variety of productive sectors outside Government. To deal with these types of firms, NAICS codes are used to assign these firms to appropriate final aggregated sectors. NAICS codes were aligned with their corresponding SIC codes and aggregated into their appropriate final sectors. To accomplish this, average quarterly employment data from QCEW data is used and distributed using the wage ratios calculated above.

The technical methods for the above section follow. First, the firms with an SIC code of 9999 are placed into a separate Microsoft Excel worksheet and used to calculate average quarterly employment for each firm is calculated. Note: Due to the fact that the wage distributions from UI data gave employment numbers higher than QCEW data, the methods used for firms with no wage distributions and 9999 SIC firms was reapplied to the firms with wage distributions and the employment was portioned out using the wage ratios that were originally calculated using their wage distributions. This was accomplished using similar programs for firms with no wage distributions and 9999 SIC firms. The final annual employment data was calculated by the taking the average of employment across the four quarters.

Land and Capital Data

Land and capital data come from the Larimer County Assessor. The Assessor's data consists of a number of key variables. The first variable of interest is the Parcel Number. A Parcel Number is assigned to each parcel of land in the county. The Abstract Code is a classification code for the organization of parcels. Abstract Codes are one of two ways to place land into one of the final sector aggregations or into residential land. Also, this is accomplished using Location City. It is of note that the Abstract Code may contain an "L" after the number denoting "land". The other method is to attempt to link land parcels to individual firms using firm name. The Assessor's data lists "BUSINESSNAME", while QCEW data lists "LEGALNAME" and "TRADENAME". The QCEW firm names are linked to Assessor's firm name and the corresponding parcel is places into its appropriate final aggregated sector. Once these parcels are organized into their final sectors land and capital values are determined.

The final variables of interest from the Assessor's data will be described below. "ACCTTYPE" is comprised of two main subsections: Commercial and Personal. The Commercial subsection denotes external capital as in building capital whereas the Personal subsection denotes internal capital as in machines, computers, etc. "VALUETYPE" is also comprised of two subsections: Investment and Land. Investment denotes capital and land is land. The final variables are "ACRES" and "ACTUALVAL". These values are then summed in accordance with either land or capital designations.

The above process does not provide information for all firms therefore, a final adjustment must be made. The capital and land data were increased be the percentage to achieve the number of firms in the QCEW data. Other small adjustments were made. Residential land was treated in the same manner. The divisions in residential were HS1, HS2, HS3, HS4, Apartment, Plexes, and Condos.

Local Government Data

The Local Government Data comes from two sources: The Comprehensive Annual Fiscal Report (CAFR) for 2004 and the City of Fort Collins wage data. The CAFR provides tax and expenditure data for city sectors whereas the City of Fort Collins provides data on employment and wages for the city sectors. These data sources are straight forward. The CAFR provides Sales, Use, Property, and other (ORV) taxes as well as total expenditure for each of the city services. Property tax is divided first into commercial and residential and then weighted by total value of land and capital for each sector and housing service. The City of Fort Collins wage data is aggregated the same way the productive sectors are aggregated. This was done manually given the small amount of data.

2.1 REFERENCES

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3. DENSITY AND THE URBAN INDUSTRIAL MIX

3.1 INTRODUCTION

The importance of density is evident by its numerous effects on the urban environment. Ciccone and Hall (1996) empirically link higher employment density with increased productivity, while other notable studies have established relationships between greater density and higher costs of providing public services, a decrease in wage differentials, greater job-matching efficiency and a greater rate of innovation.[3] Another line of literature examines the change in urban density and the concentration of population and employment. The trend of decreasing urban density over the last several decades is well-documented; however, other studies have found that population and employment have been concentrating into cities and metropolitan counties.[4] Both trends are able to coexist as cities are annexing land faster than they are adding population.[5] Declining urban density and the spatial expansion of cities have been attributed to a broad range of factors from specifics such as government polices including federal mortgage insurance and the development of the Interstate Highway System to more general trends such as decreasing transportation costs and the rise of the automobile to an expanding population and increases in household income.[6] Regarding growth, individual productive sectors within the urban industrial mix vary in structure such as land and labor intensity, the composition of employment from low to high wage workers and the distribution of sales to local consumers or exports. All of these characteristics can and do contribute to a sector's effect on density. The current research on density has examined either the changes or effects of density. No study has simultaneously analyzed both.

[3] Ladd (1992), Wheeler (2004), Hynninen and Lahtonen (2007), Carlino, Chatterjee and Hunt (2007).
[4] See Chatterjee and Carlino (2001), Bryan, Minton and Sarte (2007), Beeson and DeJong (2002), Desmet and Fafchamps (2005).
[5] Fulton, Pendall, Nguyan and Harrison (2001)
[6] Mieszkowski and Mills (1993), Glaser and Khan (2001), Brueckner (2000).

This paper uses a data-intensive computable general equilibrium (CGE) model with extensive sectoral and residential land data to simultaneously estimate the changes and effects of density that result from relative variations in urban industrial composition concentrating on the differences between manufacturing and service sectors. This research demonstrates that identical increases in aggregate metropolitan employment originating from growth in individual productive sectors result in different average urban density measures. The CGE framework is ideally suited for this research as land use decisions from productive sectors and households are analyzed under profit and utility maximization and independent of local government policies regarding annexation, thus providing results under optimality. Another benefit is that no spatial structure of the city is assumed such as monocentric.

The results bridge much of the existing literature. The research finds that service sectors support higher urban densities than manufacturing sectors. This result is important as Chatterjee and Carlino (2001) use employment density as an indicator of congestion level and predict that increases in aggregate metropolitan employment causes more employment deconcentration across metropolitan statistical areas (MSAs) than was actually observed. This suggests that an offsetting mechanism is keeping density relatively high. Desmet and Fafchamps (2005) find that service sectors are concentrating into areas of high aggregate employment such as cities while manufacturing sectors are moving away. This research suggests that the lessening of employment deconcentration across and within MSAs is due, in part, to the changing industrial composition of cities away from manufacturing and toward services. The changing industrial composition may help explain long-run average density trends presented in Kim (2007) as the results are embedded in the structure of sectors. The paper also demonstrates that sector growth under optimality has the ability to spatially expand the city and reduce population density. This result supports the caution by Brueckner (2000) of restricting the spatial dimensions of a city.[7] Another important result is that commercial density (employment per commercial acre) increases with some service sectors. This suggests increased interaction of workers and that coveted production externalities such as knowledge spillovers may still exist though overall employment density may be decreasing and that commercial density may be a more appropriate indicator of these effects. Finally, the paper simultaneously calculates the effects of density on city variables such as productivity and tax revenue measures. The productivity results suggest that a number of urban variables may benefit further econometric studies of the relationship between density and productivity whereas the tax revenue results suggest that cites may be fiscally challenged to provide the same level of public service with the changing industrial mix.

The paper proceeds as follows: Section 2 reviews density in the literature. Section 3 describes the model and simulations. Section 4 presents the results. Section 5 provides sensitivity analysis and the last section concludes.

3.2 DENSITY IN THE LITERATURE

Regarding population, earlier research is conflicted as to the evolving trend.[8] Beeson and DeJong (2002), however, find that population experienced deconcentration before 1900, but that population has been concentrating since, especially in the post-WWII period. Their result is contingent on controlling for the "frontier effect" or the

[7] Bruecker (2000) does, however, caution against *excessive* spatial expansion that is due to market failures.
[8] See Long and Nucci (1997) for review.

exclusion of western counties that have grown quickly to reach their steady state and the degree of agglomeration moving from the state to the county level. Beeson, DeJong and Troesken (2001) conclude that population is concentrating in the most densely populated counties and that the industrial mix of a county has a significant effect on population growth.[9] With specifics to population density, Bryan, Minton and Sarte (2007) compile a panel data set from 1940 to 2000 on urban population density for U.S. cities and estimate a downward shift of the distribution regarding city density that is independent of region, meaning urban density has been steadily declining. Kim (2007) examines long-run trends in average density between 1890 and 2000, and finds that average density in cities rose between 1890 and 1950 and fell between 1950 and 2000. Fulton, Pendall, Nguyan and Harrison (2001) determine that most metropolitan areas are adding land faster than population. They find correlations with population density and regional variables such as population size (the more populated areas tend to be denser) and land type (geographically constrained or areas surrounded by prime farmland tend to be denser). They test, but find no correlation between manufacturing employment and density.

Regarding employment, Chatterjee and Carlino (2002) find employment deconcentration in the postwar era both across and within MSAs. Using employment density as an indicator of congestion level, Chatterjee and Carlino (2001) predict that an increase in aggregate metropolitan employment results in more deconcentration than was actually observed and suggest that something has offset the rising costs of congestion that is keeping density relatively high.[10] Desmet and Fafchamps (2005) find that total

[9] They note that this may be due to the rise of manufacturing during their sample and that counties with larger shares of this industry simply benefited from this.

[10] They offer a reinterpretation of former studies that have alluded to deconcentration, namely those of Garnick and Renshaw (1980), Colman (1978) and Leven (1978).

employment is becoming increasingly concentrated at the county level and that service sector jobs have moved to areas of high aggregate employment such as metropolitan counties and cities, whereas non-service jobs have moved away from employment clusters. Desmet and Fafchamps (2006) argue that employment deconcentration is limited to the upper 8% of the distribution of counties ranked by total employment, whereas the remaining distribution exhibits concentration. Kolko (1999) finds that services are over-represented in cities and that increases in information technology is expected to continue this trend. Key, Pratt and Warner (2007) review the changing industrial structure toward services and conclude that services are an importance element in regional economic development.

In turning to the effects of density on the urban environment, Ciccone and Hall (1996) state that employment density can affect productivity through reduced transportation costs, production externalities and/or specialization. They find that a doubling of county employment density increases labor productivity by 6% at the state level. This result was reproduced at the metropolitan level by Harris and Ioannides (2000) using population density and wage income. Density also has an effect on the cost of providing city services. There is a debate between city planners and economists as to whether population density will increase or decrease the cost of providing public services such as water supply, police, waste collection, and traffic management. Wheaton and Schussheim (1955) are the first to link high-density and lower public sector costs, while the most widely cited is the Real Estate's Research Corporation's (1974) study. Other research contradicts this assertion suggesting that at higher densities the local area faces a "harsher environment", more traffic lights and more technicians are required for service;

more complicated sewer and transportation systems must be designed and built; higher densities may lead to a higher crime rate thus requiring additional police officers.[11] Ladd (1992) distinguishes the cost of *producing* a given level of final goods, and the cost of *providing* a given level of final goods. She estimates a U-shaped relationship between public spending on local services and population density suggesting fiscal burdens on local residents must increase or face decreased local services. With the exception of very low densities, the cost of providing public services increases with density.

To summarize density in the literature, population and employment are concentrating in urban counties and cities, while urban density has been decreasing. Cities are annexing land faster than they are adding population allowing both of these trends to coexist. The urban industrial mix is transitioning to a post-industrial service economy as service sectors have been concentrating in areas of high aggregate employment while non-service sectors have been moving out. The effects of increased urban density have been shown to increase labor productivity and increase the cost of providing public services.

3.3 MODEL SPECIFICS

The elasticities used in the model are taken from existing literature. Berek et al. (1996) provides an extensive literature survey on labor supply elasticities for differentiated household groups. They conclude labor supply elasticities range from 0.2 for low-income households to 0.8 for upper-income households. These are the elasticities used in the model. Larger labor supply elasticities lead to higher density measures as less

[11] See Bradbury et al., (1984) and Ladd and Yinger (1989).

pressure is put on wages which generates less real household income leading to relatively less residential land use.

As for land supply elasticities, Blackley (1999) used U.S. data to estimate long-run elasticities between 1.6 and 3.7. Malpezzi and Maclennan (2001) estimate supply elasticities post WWII between 6 and 13. Green, Malpezzi and Mayo (2005), using the model developed by Mayer and Somerville (2000), estimate metropolitan-specific supply elasticities for 45 cities ranging from (–0.3) for Miami to 29.9 for Dallas. They find that cities that are geographically constrained, heavily regulated, have high population density or not growing result in lower elasticities. This paper uses 6.0 for land supply elasticities. As expected, lower land elasticities increase density measures. This has policy implications that will be explored in the sensitivity analysis section.

Migration elasticities with respect to real income and unemployment are set in accordance with Schachter and Althaus (1989) with the in-migration real income elasticity set at 4.61 and the unemployment component set at (–2.7). Renkow and Hoover (2000) estimate commuting elasticities with respect to wage range from 0.116 for rural-to-metro commuting and 0.257 for metro-to-metro commuting. The commuting elasticity in this paper is set at 0.2. These elasticities produce results consistent with Bartik (1993) that migrating workers fill around 75 percent of new jobs. Greenwood and Hunt (1984) analyze 57 labor markets and find that migrating workers fill between 20 and 80 percent of new jobs; therefore, smaller and larger migration elasticities are examined to account for this. Higher migration elasticities lead to higher density measures. This also has policy implications that will be explored in the sensitivity analysis section.

To summarize the choice of elasticities, while the model is dependent on outside literature to determine specific values used in the model, the results of the paper are robust across elasticity values. The results are embedded in the structure of individual sectors not the specific parameter values, though these parameter values do have policy implications that are important to cities whose characteristics reflect these values.

Sectors and Land Model Specifics

A couple of notes concerning a few sectors should be mentioned. The Manufacturing and Computer Manufacturing sectors are predominantly standardized in production and are land-intensive. While Computer Manufacturing engages in more R&D activities, it is not dominated by smaller, diverse firms as found in larger cities. Housing services are modeled as independent sectors similar to Pasha and Ghaus (1995). They demand inputs from Construction, FIRE, land and capital. Therefore, as FIRE expands through export, capital or TFP growth, housing services are directly affected. For example, if FIRE experiences export growth, its price increases resulting in the price of housing services increasing and dampening demand and residential land use.

Regarding how land is handled in the model, the public use of land (streets, parks, etc.) is not modeled. The public use of land is expected to increase with growth; however, the amount of land is primarily determined by policy. While the model does include agricultural/ranch land, the density measures do not, as density is typically calculated per urbanized acre. The model also does not account for excess capacity or available vacant land in the city that may be substituted for new land. In other words, only commercial and residential land that is currently occupied is used in the model. The model does not assume fixed lot size of sectors or households; therefore, they can alter their use of land without changing lots. Both vacant land and fixed lot size would affect the magnitude of density measures, but would not affect the results of the paper. The impact of vacant land is examined below whereas the assumption of fixed household lot size is examined in the sensitivity analysis section.

3.4 SETTING UP THE SIMULATIONS

The simulations use Chatterjee and Carlino (2001) as motivation by standardizing over aggregate metropolitan employment. The method will increase aggregate employment by an identical amount through growth originating from different individual productive sectors. Table 1 provides some descriptive characteristics of the sectors. The sectors used in the simulations are the manufacturing-related sectors: Computer Manufacturing, Manufacturing and Wholesale (Wholesale is considered manufacturing-related as it encompasses 13.1% of total intermediate demand versus only 3.9% to household consumption and 83.4% of its intermediate demand goes to Manufacturing or Computer Manufacturing. Another perspective is that 67.1% of Wholesale's local sales are to Manufacturing or Computer Manufacturing whereas only 15.7% are to local households) and the service-related sectors: FIRE, High Services, Lodging and Retail. While most sectors are self-descriptive, High Services includes services in medical, legal, computer, management and engineering. The Lodging sector is a key sector in the tourism industry and is viewed as a proxy for it. High Services employs the highest percent in the economy at 13.3% with Lodging the least at 1.3%. Computer Manufacturing has the highest average wage at $60,500. Retail is the largest portion of household consumption at 24.8%. Manufacturing is 38.7% of intermediate demand. Manufacturing uses the most land at 232.7 acres followed by Wholesale at 151.3 acres. Also presented in Table 1 are the average employment growth rates using time series data for Larimer County from 1990 – 2006 where Fort Collins is the largest economy in the county.[12] The growth rates are consistent with the finding of Desmet and Fafchamps (2005) in that Computer Manufacturing and Manufacturing have negative values whereas the service sectors are expanding.

The first decision regarding the simulations is the level of the aggregate metropolitan employment level on which to standardize. The value of 100 additional aggregate workers was chosen for the simulations due to the limitations imposed by the size of the Lodging sector. The results of the paper are robust at higher aggregate employment levels. The second decision is the type of regional growth to implement. Regional growth can be categorized into three main processes: employment, productivity and population growth [see Burnett, Cutler and Davies (2008)]. Employment and productivity growth can be estimated on a sector-specific basis. Population growth is not sector specific, but is also analyzed as both people follow jobs and jobs follow people.[13]

Employment growth can be divided into two types: export growth and capital migration or local growth. Employment growth through exports results from an increase in external demand that shifts out the sector's demand curve. The sector increases its factors of production including land and labor in order to meet increased demand with increased production. This type of growth puts upward pressure on prices. Brown, Coulson and Engle (1992) and Nishiyama (1997) find evidence for export-led growth in

[12] This data comes from Regional Economic Information Service (REIS) data.
[13] See Greenwood and Hunt (1984), Mathur and Song (2000) and Partridge and Rickman (2003).

cities across the U.S. In regards to service sector exports, Beyers and Alvine (1985) demonstrated that exports are a significant portion of sales in service sectors and Beyers (2005) shows that service sector exports have increased from 1995 to 2000, especially in health and producer services (financial, legal, etc). To implement export growth, PW0 in equation (22) is increased for a specific sector until aggregate metropolitan employment increases by 100 additional workers. For example, in the Manufacturing sector expansion, PW0 is increased for the Manufacturing sector until aggregate employment in the city expands by 100 workers. This same method is used on the other sectors.
Engle (1979) describes the second type of employment growth in which an increase in the supply or migration of capital to a region can cause economic growth. Capital migration or local growth occurs when there is an increase in the supply of capital into the city through either local residents obtaining capital via branch banking, external firms move into town to take advantage of local demand or as a result of firm location decisions. The increase of sector-specific capital reduces the price of capital and shifts out the sector's supply curve increasing the sector's demand for land and labor as output increases. Local growth is implemented by increasing KS0 in equation (12) for each sector until aggregate metropolitan employment increases by 100 additional workers.

There is extensive literature on the impact of productivity on growth which is not reviewed here.[14] Productivity changes can be divided into total factor productivity (TFP), and the marginal productivity of labor or capital (MPL or MPK respectively) of which TFP dominates.[15] Cutler and Davies (2008) examine specific impacts of each type of productivity growth and conclude that TFP results in four times as much economic

[14] See Burnett, Cutler and Davies (2008) for a discussion.
[15] Prescott (1998) and Klenow and Rodriguez-Clare (1997) are recent examples.

growth and that increases in MPL or MPK primarily results in a reallocation of resources and limited economic growth. Since this paper is interested in sector-specific growth, TFP is used to simulate productivity growth. This is accomplished similar to Jones (2000) in that $DELTA_l$ in equation (2) in increased per sector until aggregate metropolitan employment increases by 100 workers.

Population growth is also analyzed as literature has found that both people follow jobs and jobs follow people. To perform the simulations for population growth, the natural rate of population growth (NRPG), is increased in equation (8) until aggregate metropolitan employment increases by 100 workers.

Using the techniques described above, the following section presents the simulation results for density changes that include average population density (additional people per additional acre), average employment density (additional employment per additional acre) and average commercial density (additional employment per additional commercial acre). It also presents the effects of density for productivity using Ciccone and Hall (1996) as motivation by calculating the percent change in Gross City Product (GCP) with respect to percent change in employment density or the density elasticity. The effects on local tax revenue are calculated using the measure of additional tax revenue per additional person or tax revenue per capita to follow Ladd (1992) in order to compare to the established relationship of density and the cost of providing public services.

Table 3.1: Description of Sectors

	Manufacturing-Related Sectors			Service Sectors			
	Computer Manufacturing	Manufacturing	Wholesale	FIRE	High Services	Lodging	Retail
Employment (Percent of Total)	3784 (5.9%)	6007 (9.3%)	2207 (3.4%)	2078 (3.2%)	8459 (13.2%)	858 (1.3%)	4208 (6.6%)
Average Wage	$60,500	$24,880	$28,357	$16,714	$24,838	$3,703	$10,178
Percent of Household Consumption	0.1%	2.5%	5.2%	12.3%	17.7%	1.2%	24.8%
Percent of Intermediate Demand	8.8%	38.7%	13.1%	6.2%	7.6%	1.2%	0.8%
Acres	145.8	232.7	151.3	21.9	51.8	11.0	130.0
Acres per Worker	0.04	0.04	0.07	0.01	0.01	0.01	0.03
Average Growth Rate	(1.3%)	(0.5%)	4.5%	3.2%	4.0%	3.0%	3.5%

3.5 SIMULATION RESULTS

Table 3.2 shows the sector results for three types of average density: population, employment and commercial. Regarding density, the most important result lies in the difference between manufacturing and service sectors. The overall results show that service sectors support higher population and employment densities than manufacturing-related sectors. The sector that results in the lowest simulation value for population density under export growth is Wholesale (4.7 additional people per additional acre), compared to the base value of 16.2 people per acre. The Lodging and FIRE sectors have the largest population density with a simulation value of 12.7 and 9.8 respectively. The capital and TFP growth simulations produce similar values with service sectors supporting higher density values than manufacturing-related sectors; however, in these cases FIRE yields relatively lower population density due to its role in housing services. Population growth increases population density with a simulation value of 23.9 persons per acre.

Most of the simulation results lead to decreases in urban density. This is possibly due to a number of reasons concerning the way land is treated in the model. Recall that the model does not account for excess capacity or available vacant land nor does it assume fixed lot size of sectors or households. Either of these situations could increase density and will be examined later in the paper.

The employment density results parallel the population density results with service sectors supporting higher employment density than manufacturing-related sectors. Lodging increases employment density under export growth with a simulation

Table 3.2: Sector-Specific Density Results

	Manufacturing-Related Sectors			Service Sectors				
	Computer Manufacturing	Manufacturing	Wholesale	FIRE	High Services	Lodge	Retail	*Population Growth*
Population Density (16.2)								
Export	5.4	5.5	4.7	9.8	8.7	12.7	7.0	
Capital	5.7	6.1	5.0	6.2	8.0	12.0	7.2	*23.9*
TFP	6.0	6.4	5.1	6.3	8.0	12.0	7.3	
Employment Density (9.4)								
Export	4.4	4.5	4.1	8.6	7.6	12.0	6.3	
Capital	4.7	5.1	4.3	5.3	6.6	11.4	6.1	*12.2*
TFP	5.1	5.4	4.3	5.4	6.6	11.4	6.1	
Commercial Density (42.9)								
Export	40.9	24.0	9.4	78.9	1013.8	33.7	14.5	
Capital	27.6	26.5	11.6	69.2	60.5	31.8	30.4	*70.0*
TFP	31.0	28.9	11.8	70.0	60.1	31.8	31.3	

value of 12.0 compared to the base of 9.4 employees per acre. Population growth also increases employment density with a simulation value of 12.2 employees per acre.

While population and employment density generally decrease with sector expansions, commercial density provides a different perspective. Under export growth, commercial density increases dramatically with High Services (1013.8 additional employees per additional commercial acre). It also increases with FIRE (78.9) compared to the base value of 42.9 employees per commercial acre. The sectors that produce the lowest values are Wholesale (9.4) and Retail (14.5). The capital and TFP growth simulations follow the same patterns though with different intensities. High Services and FIRE still increase commercial density. Population growth increases commercial density with a simulation value of 70.0 employees per commercial acre.

In discussing density effects, it is helpful to recognize that the two sources of land are commercial and residential. Commercial land is derived from productive sectors choosing land quantity to maximize profits and residential land comes from households choosing the quantity of housing services, which includes residential land, that maximize utility. For example, an increase in export demand in the Manufacturing sector results in increased production and increased demand for land and labor. This results in higher real income to households as wages increase faster than prices.[16] As real income increases and households migrate to the city, local sectors such as Low Services (cleaning, repair, beauty, daycare services, etc.) and Restaurants benefit and increase their use of land. While some sectors benefit, other do not are crowded out of both labor and land. The higher real income also results in resident households consuming more housing services

[16] Cutler and Davies (2007).

resulting in more residential land. Residential land also increases with the in-migration of households.

The causes behind the sector-specific density results will focus on the difference between manufacturing and service sectors and can be organized into four major effects: production, price, income and migration. The production effect involves the use of land in production or the degree of land-intensiveness. A land-intensive sector requires more commercial acres as it expands which puts downward pressure on density values. The price effect involves the sector's effect on local price level (local CPI). The local price level is affected by the sectors' sales distribution. Sectors that sell more locally (i.e. service sectors) have a greater impact on the local price level, which can affect density through the degree of crowding out. The income effect deals with changes in real household income. As real household income increases, local households can afford more local goods and housing services (residential land), which puts downward pressure on density measures. Finally, the migration effect can influence density measures. Higher wage in-migrants lead to less crowding out due to greater consumption of local goods and the ability to consume more housing services, both decreasing density values compared to low-wage in-migrants. The following analysis looks at these effects from a sector- specific perspective. Summary tables for individual sectors under export, capital and TFP growth are found in Tables 3.7, 3.8 and 3.9 in the appendix for Chapter 3.

First, manufacturing-related sectors are the most land-intensive sectors in terms of gross land use and acres per worker measures (see Table 3.1); therefore, as these sectors expand they require larger amounts of commercial land for own production. Retail is also, land-intensive primarily due to the influence of big-box retailers. Under export growth, Wholesale uses the most own sector land use at 11.4 acres. Retail (7.3) and Manufacturing (3.6) are the next largest consumers of land for own sector use. While Retail uses the second most own sector land, its density effects are affected by its price, income and migration effects to be discussed below. The service sectors such as High Services and FIRE use the least at 1.1 and 2.0 acres respectively. The same production effects are also evident in the capital and TFP expansions. Therefore, own commercial land use in the expanding sector increases more, on average, for manufacturing sectors than services save for the land-intensive sector of Retail.

This production effect along with the labor-intensiveness of the sector is primarily responsible for the differences in the commercial density results. High Services uses little commercial land, but is highly labor-intensive. This results in a large commercial density measure. The same logic is true for FIRE, giving this sector a high commercial density value. The land-intensive manufacturing-related sectors and Retail yield low commercial density values.

The next effect is the price effect. When a sector expands, the local CPI is affected by the portion of sales that are exported and both its involvement in intermediate demand and household consumption. Manufacturing-related sectors are more export-oriented and have a higher percent of sales to intermediate demand, while services sell more locally (exports average around 30% of sales). The result under export growth is that service sectors, on average, increase local CPI more than manufacturing-related sectors. The exception is Manufacturing due to the fact it is 38.7% of intermediate demand. Retail (0.06%) increases local CPI the most. The increase in local prices under export growth results in crowding out in sectors that do not indirectly benefit.

Households spend according to their consumption patterns, which, as demonstrated, are primarily local services. Therefore, with service expansions, there is generally less indirect benefit compared to manufacturing-related expansions. This effect is seen in the indirect land effects in Table 3.7, 3.8 and 3.9. On the capital and TFP growth sides, given that it they are a supply-type expansions and that prices in the expanding sector generally fall for service sectors, the opposite of the export case occurs resulting in positive indirect land effects; however, service sectors still support higher density measures. This is due to the lower magnitude of shock needed to generate 100 aggregate workers as lower prices yield less crowding out in indirect sectors. The next effect, the income effect, can help explain the large increases in indirect commercial land effects from Computer Manufacturing and Manufacturing under capital and TFP growth.

An increase in real income to households allows local households to consume more local goods and services as well as housing services. Prices and wages affect real income and the sectors with the highest wages are Computer Manufacturing, Manufacturing and Wholesale (see Table 3.1). Service sectors are predominately low-wage, save High Services. Due to these wage effects, manufacturing-related sectors increase real household income greater than service sectors. The sector that produces the largest percent gain under export growth is Computer Manufacturing at 0.35%. The sectors with the lowest gain are Lodging at 0.11% and Retail at 0.19%. This same trend is found under capital and TFP growth with manufacturing-related sectors yielding higher increases in real income compared to services, though the difference is less due to the price effect of supply-type expansions in services.

This increase in real income contributes to the higher indirect commercial land effects for manufacturing-related sectors as more local goods and services are consumed. More importantly, local households consume more housing services and, therefore, residential land. Residential land demand comes from both existing households and new households migrating to the city. The sectors that result in the largest increase in total residential land use under export growth are Computer Manufacturing (21.9 acres), Manufacturing (17.9) and Wholesale (13.8). The lowest residential land comes from Lodging (5.2) and Retail (9.0). Under capital and TFP growth, the results are less drastic between manufacturing-related and service sectors. In fact, due to their role in housing services, FIRE now yields the largest residential land use at 17.6 and 17.1 acres respectively.

The final effect is the migration effect. The change in real income affects net migration (see equation 25). As real income increases, more in-migrants are attracted to the local economy, thus manufacturing-related sectors attract more in-migrants than services. These numbers are reported in Tables 3.7, 3.8 and 3.9 and are consistent with Bartik (1993) in that migrating workers fill around 75 percent of new jobs. While it is true that more in-migrants in the same sector-specific expansion increase density measures (as explored in the sensitivity section with larger migration elasticities), this result does not hold for manufacturing-related versus service sectors. Due to less in-migration, as service sectors expand, they must pull more workers away from other sectors causing greater crowding out in both labor and land. Also, the manufacturing-related sectors pay higher wages that bring in a different distribution of households, namely they bring in higher income households compared to the low-wage services.

This has two effects, first, greater local goods and services are consumed by manufacturing-related sectors resulting in less crowding out. Second, the households from manufacturing-related sectors consume a higher level of housing services and residential land. These differences contribute to manufacturing-related sectors decreasing population and employment density to a greater degree than services.

An intriguing result regards the effect on overall population in the city. Even though manufacturing-related sectors reduce density greater, on average, than services, overall population increases more with manufacturing-related sectors (see Tables 3.7, 3.8 and 3.9). The increase in real income due to the high-wage nature of manufacturing-related sectors draws more in-migrant workers, who move into the city and bring with them other members of their household resulting in higher population.

As discussed, the model does not take into account the availability of vacant land. Any substitutability of vacant land will increase the density measures presented in Table 3.2. Tables 3.7, 3.8 and 3.9 provide the total additional land required to achieve profit and utility maximization. With regards to vacant land, the percentage of this total land use that is required to keep population density constant in the city is also reported. If more vacant land is used than these percentages, population density will increase in the city.

To summarize the density effects, service sectors support higher density measures for population and employment than manufacturing-related sectors. Commercial density increases dramatically with High Services, and also increases with FIRE. These results are due to four main effects: the production nature of the sector, the more land-intensives the more downward pressure on density; the effect on the local price level, under export growth it generally increases more with services due to their role in household consumption; real income increases more with manufacturing-related sectors due primarily to their higher wages; and the type of in-migration is different with higher wage migrants from manufacturing-related sectors causing less crowding out and more residential land use.

Discussion of Sector-Specific Density Effects

Given identical increases in aggregate metropolitan employment, service sectors support higher population and employment densities than manufacturing-related sectors. This result may yield some insight into the current density trends that exist in the literature. Chatterjee and Carlino (2001) find that aggregate employment growth alone predicts more deconcentration that actually observed. They suggest a reinterpretation of former studies that have alluded to deconcentration of employment through changes in technology, polices and/or preferences. This paper argues for another possibility: the transition of the urban industrial mix away from manufacturing and toward services as the economy transition from an industrial to a post-industrial service-based economy. Dement and Fafchamps (2005) support the transition of the urban industrial mix as they find that service sectors are moving to areas of high aggregate employment such as cities, whereas non-service sector jobs are leaving. Kolko (1990) finds that service sectors are over-represented in cities and that advances in technology is expected to continue this trend.

Population density can decrease with all sector growth and increases with population growth. This assumes no vacant land is used and households not having fixed lot size. The differences in sectors and industrial composition may help explain the long-run trends in average density in Kim (2007) as the results are embedded in the structure of sectors, though further research is needed. Fulton, Pendall, Nguyan and Harrison (2001) test but find no correlation between manufacturing employment and density. This research shows that sectors do have unique impacts on density and that manufacturing sectors put greater downward pressure on density than services.

Brueckner (2000) cautions against constraining the spatial expansion of cities that is not due to market failures. This research shows that the city expands by various total land use depending on sector and type of growth. The results also demonstrate that decreasing population density may be optimal and that restrictions on the city to increase population density may decrease household welfare.

The Effects of Density on Urban Characteristics

As mentioned, urban density has numerous effects on the urban environment. This paper simultaneously analyzes two of these effects: density elasticity and tax revenue per capita. First, sector-specific density elasticity is calculated. This measure follows Ciccone and Hall (1996) by calculating the percent change in real Gross City Product (GCP) per worker over the percent change in employment density. The base value of GCP/worker in the model is $36,350. Ciccone and Hall (1996) find that a doubling of employment density results in a 6% increase in labor productivity or a 0.06 density elasticity. They argue that density can affect productivity through reduced transportation costs, production externalities and/or specialization. This paper does not address the causes of this relationship; rather it suggests that this relationship can be affected at the city level by a number of urban variables such as relative variations in the industrial mix, the type of urban growth, the rate of population growth and different land elasticities, which are a function of geographic constraints and local land-use regulation.

Table 3.3 gives the simulation values for the density elasticities across individual sectors as well as population growth. It is not surprising that the majority of these elasticities have a negative sign as the causes of this relationship are not modeled and that the model does not have excess capacity of land which affects employment density; however, the results do show a wide range of values both across sectors and types of growth. As discussed, all sectors save Lodging under export growth decrease employment density. Under export growth GCP/worker generally decreases due to the increasing price effect causing crowding out. This results in positive values for many of the sectors with Wholesale, FIRE and Retail producing an elasticity value close to the literature. This is not the case for Manufacturing and Computer Manufacturing under export growth as GCP/worker increases leading to negative density elasticities. The decreasing price effect from supply-type capital and TFP growth increases GCP/worker for all sectors save Lodging resulting in negative elasticities with the largest values coming from Computer Manufacturing and Manufacturing. These results demonstrate that the estimated density elasticity is sensitive to relative growth in the industrial mix and the type of growth experienced.

Population growth produces a negative elasticity, but for a different reason. Employment density increases under population growth while GCP/worker decreases. Due to the opposing effects of sector growth and population growth, the result of Ciccone and Hall (1996) can be reproduced by combining the two. Table 3.3 shows the growth rate of population needed to reproduce 0.06 for the density elasticity for each sector.

Table 3.3: Sector-Specific Productivity and Tax Revenue Effects

Sector	Manufacturing-Related Sectors			Service Sectors				Population Growth
	Computer Manufacturing	Manufacturing	Wholesale	FIRE	High Services	Lodge	Retail	
Density Elasticity								
Export	(0.48)	(0.66)	0.11	0.13	0.40	(1.97)	0.13	(1.20)
Capital	(5.19)	(3.86)	(0.30)	(0.30)	(2.16)	(1.27)	(0.65)	
TFP	(4.55)	(3.52)	(0.30)	(0.28)	(1.99)	(1.27)	(0.61)	
Growth Rate of Population								
Export	0.47%	0.61%	(0.06%)	(0.005%)	(0.07%)	n/a	(0.03%)	
Capital	over 6%	over 6%	0.34%	0.23%	0.76%	n/a	0.31%	
TFP	over 6%	over 6%	0.31%	0.20%	0.69%	n/a	0.29%	
Tax Revenue Per Capita *Base: $797*								
Export	$5,958	$7,769	$1,349	$2,017	$2,114	$7,673	$6,973	$1,139
Capital	$6,289	$7,134	$1,678	$1,980	$1,902	$4,001	$2,250	
TFP	$7,588	$7,556	$2,035	$2,098	$2,493	$3,994	$2,562	

For example, under export growth, the Computer Manufacturing sector expansion would need a growth rate of population of 0.47% to reproduce the productivity elasticity of 6%. Lodging under export growth is the only case in which the result cannot be reproduced as both have the same effect of increasing employment density and decreasing GCP/worker.

Along with population growth, land elasticities also affect this result. Naturally, lower land elasticities yield higher employment density. Unlike the growth rate of population, specific land elasticity values are not possible to calculate for all sectors, but in some instances they are available. For example, under export growth for Manufacturing and Computer Manufacturing, GCP/worker increases and employment density decreases. Lowering the land elasticity from the base level of 6.0 used in the original simulation to 0.14 and 0.04 respectively will increase employment density and yield a density elasticity of 0.06. Also under export growth, for High Services a land elasticity of 20.3 will reproduce this result. As mentioned, Green, Malpezzi and Mayo (2005) estimate land elasticities that range from (-0.30) to 29.9 depending on a number of urban characteristics including geographic constraints, land-use regulation and urban form (population density). These results suggest that controls these urban characteristics may benefit further econometric studies on the relationship of density and productivity at the city level.

Along with productivity, density has also been shown to affect the cost of providing public services. While the model does not estimate this cost, it can lend some insight into what the city can expect in terms of collecting tax revenue. Following Ladd (1992), additional tax revenue per additional person or the simulation value of tax revenue per capita is calculated. These results are presented in the bottom half of

Table 3.3. With regards to tax revenue per capita, the efficiency measure increases across the all sectors and types or growth. The largest values come from Manufacturing and Computer Manufacturing due to property taxes. The lowest values are from Wholesale and the service sectors of FIRE and High Services. Population growth produces a value close to the base though increases all three measures of density.

The results suggest that growth in all sectors generate tax revenue per capita above the base; however, all sectors are not growing. The literature and data demonstrate that the tax-intensive sectors of Manufacturing and Computer Manufacturing are declining and leaving employment clusters and cities. The analysis of decreases in these sectors is explored next.

Analysis of Decrease in Manufacturing and Computer Manufacturing

Both the literature and the data used in the model denote the decrease in manufacturing employment. This subsection analyzes the impact of a decrease in the two sectors Manufacturing and Computer Manufacturing and will focus on the changes in population density and tax revenue per capita to further explore the analysis between density and local government finances. The analysis is accomplished by reducing employment in each sector by the average percentage employment loss presented in Table 3.1. The method will use two scenarios: a decrease in exports by decreasing PW0 in equation (13) representing a decrease in demand and a by reducing KS0 in equation (25) representing a decrease in capital as firms in these sectors leave the city. A decrease in TFP is not examined as these sectors are not becoming less productive.

The initial results of a decrease in Manufacturing and Computer Manufacturing are presented in Table 3.4. The table depicts the effect on population density in two cases. The first case allows for the city to contract by losing land that is no longer used by the contracting sector and households that move out of town. In both sectors, this case would increase population density. However, this case is unlikely as the land becomes vacant and still within city boundaries. Under this second case the decrease in both sectors lead to decreasing population density. This case is supported by the findings of Wheeler (2004) that a decrease in population density is correlated with a decrease in manufacturing.

The tax revenue measures are concerning for city governments as these sectors contribute a large portion of local tax revenue due to property and use taxes. The results show that the loss of tax revenue per capita is greater than the base values. For example, in the Manufacturing export contraction the simulation value of tax revenue per capita is (-$ 7,843) compared to the base of $792. This means that as Manufacturing contracts, tax revenue per capita decreases. This result occurs for Computer Manufacturing contractions. The contraction results find that population density and tax revenue efficiency measure decrease with the contraction of Manufacturing and Computer Manufacturing; however, the contractions generate vacant land within the city and the literature demonstrates that services are replacing the loss of manufacturing in cities.

Therefore, another set of simulations is performed that replaces the vacant land generated by Manufacturing with different service sectors. For example, the export contraction of the Manufacturing leads to a loss of 7.2 acres of land under profit and utility maximization and 19.2 acres under export contraction of Computer Manufacturing.

Assuming this land is now vacant, expansions in the service sectors of FIRE, High Services, Lodging and Retail are performed to increase total land use by this acreage. In other words, expansions in the service sectors are performed until total land use has a net gain of zero. Table 3.5 presents these results of replacing the land vacated by Manufacturing with the service sectors of FIRE, High Service, Lodging, and Retail respectively. Computer Manufacturing contractions are similar and the results are suppressed to save space.

The results in Table 3.5 are discouraging for city governments as services replace manufacturing in cities, the general results suggest that population density increases, but tax revenue per capita decreases. This is particularly true with FIRE and High Services. Under the FIRE expansion from capital and TFP, population density remains relatively constant, but tax revenue per capita falls significantly. Ladd (1992) demonstrated that local public spending increases with increased population density. These results suggest that local governments are fiscally strained given the contraction of manufacturing and expansion of services. However, there is one case in which local finances may benefit. This case is export expansions in Lodging.

Table 3.4: Decrease in Computer Manufacturing and Manufacturing

	Computer Manufacturing		Manufacturing	
	With Land Decrease	No Land Change	With Land Decrease	No Land Change
Population Density				
Export	0.19%	(0.09%)	0.07%	(0.04%)
Capital	0.27%	(0.14%)	0.10%	(0.06%)
Employment Density				
Export	0.16%	(0.13%)	0.06%	(0.05%)
Capital	0.21%	(0.20%)	0.08%	(0.09%)
Commercial Density				
Export	0.01%		0.04%	
Capital	0.11%		0.06%	
Tax Revenue per Capita: *Base: $797*				
Export	($5,971)		($7,843)	
Capital	($6,482)		($7,237)	

Table 3.5: Decrease in Manufacturing Replaced with Services

	Manufacturing			
	Export		Capital	
	Population Density	Tax Revenue Per Capita	Population Density	Tax Revenue Per Capita
High Services				
Export	0.02%	(0.22%)	0.03%	(0.35%)
Capital	0.02%	(0.24%)	0.02%	(0.39%)
TFP	0.02%	(0.20%)	0.02%	(0.33%)
FIRE				
Export	0.03%	(0.21%)	0.04%	(0.34%)
Capital	0.004%	(0.25%)	0.001%	(0.41%)
TFP	0.005%	(0.25%)	0.001%	(0.40%)
Lodging				
Export	0.05%	0.48%	0.08%	0.78%
Capital	0.04%	0.002%	0.06%	(0.07%)
TFP	0.04%	0.02%	0.06%	(0.04%)
Retail				
Export	0.01%	(0.02%)	0.01%	(0.05%)
Capital	0.01%	(0.23%)	0.01%	(0.37%)
TFP	0.01%	(0.21%)	0.01%	(0.34%)

In this case, the increase in tax revenue per capita is greater than the increase in population density. While the export expansions of Lodging yield this result, the capital and TFP expansions do not. The results suggest that if cities can increase exports of Lodging (via Tourism), they may be able to offset the loss of tax revenue per capita due to the contractions of Manufacturing and/or Computer Manufacturing.

3.6 SENSITIVITY ANALYSIS

The sensitivity analysis section analyzes three elements: the assumption of fixed household lot size and the effect of differing elasticities of land and migration. The original analysis does not assume fixed lot size of households and allows resident households to consume more residential land. While this is true in some cases, as real income increases some households move into larger houses with more residential land, but this is not the case for all households. Table 3.6 provides the results on density given the assumption of fixed household lot size which is accomplished by setting the land elasticity on housing services to zero and assigning average residential land use to migrating households per income group. The general results of the paper hold and in some cases such as employment density become more pronounced further supporting the result that services support higher employment densities than manufacturing-related sectors. In the case of population density, the FIRE results stabilize and increases population density in every growth case. The same is true for High Services, which yields the highest population density values under export growth. Lodging and Retail typically yield higher values than the manufacturing-related sectors save the case of an export expansion in Retail. This is due the increase in local CPI which crowds out local

Table 3.6: Sector-Specific Density Changes (Fixed Household Lot Size)

	Manufacturing-Related Sectors			Service Sectors				
	Computer Manufacturing	Manufacturing	Wholesale	FIRE	High Services	Lodge	Retail	*Population Growth*
Population Density (16.2)								
Export	14.6	12.3	7.0	18.9	22.9	14.4	9.4	*17.7*
Capital	12.8	12.9	8.0	18.3	17.7	14.0	13.5	
TFP	13.5	13.4	8.1	18.3	17.6	14.0	13.6	
Employment Density (9.4)								
Export	11.7	10.0	6.1	16.8	20.0	13.8	8.5	*8.9*
Capital	10.6	10.7	6.9	15.7	14.5	13.3	11.4	
TFP	11.3	11.3	7.0	15.8	14.6	13.3	11.5	
Commercial Density (42.9)								
Export	39.6	22.3	8.9	79.2	*	32.9	13.7	70.0
Capital	26.2	25.0	10.9	69.0	59.8	31.0	29.0	
TFP	29.6	27.3	11.0	69.9	59.4	31.0	29.9	

* Assuming fixed household lot size makes total commercial land use negative

sectors. Regarding tax revenue per capita, this measure remains relatively constant under fixed lot size.

The next analysis focuses on land elasticities. Following Green, Malpezzi and Mayo (2005), land elasticities in the model are decreased to 1 to represent restricted cities by either geographical boundaries or heavily regulated such as Albany, Pittsburg, Toledo and San Francisco (see also Malpezzi 1996) and increased to 20 to represent "sprawl cities" such as Dallas, Phoenix, Atlanta, and Charlotte. The results are suppressed as both elasticities respond as expected with a few changes. With low land elasticities, all density measures (population, employment and commercial) increase and high elasticities decrease densities which is constant with the findings of Fulton, Pendall, Nguyan and Harrison (2001) in that geographically constrained areas or areas surrounded by prime farmland tend to be denser.

Different land elasticities do change a few results. With regards to employment density, high land elasticities now reduce employment density for Lodging under export growth and Population growth instead of increasing as it did under the original simulations. There are a number of changes with commercial density. With low land elasticities, commercial density now increases for Computer Manufacturing under export growth and both types of growth for Lodging and capital growth for Retail. These results suggests that strict local land regulation may increase the strain on local finances as they put upward pressure on population density while tax revenue per capita measure remain relatively constant.

The final sensitivity analysis deals with the elasticity of migration. Areas that possess greater amenities, whether they are natural amenities such as climate or produced amenities such as theater and shopping access, are more attractive to households. This is reflected in higher migration elasticities. Given these conditions, the results of the paper are not affected with different migration elasticities, only the magnitude of the results. The results suggest that areas with higher amenities face higher density measures as more households are attracted to the area; however, tax revenue per capita measure are lower than original values.

The implications of the sensitivity analysis section are that a number of conditions may further exacerbate the fiscal conditions faced by cities. Fixed household lot size, lower land elasticities (stricter local land regulation) and greater amenities all put upward pressure on population density while tax revenue per capita values remain relatively constant or are decreasing; therefore, these characteristics may intensify the strain on local governments to provide the same level of local services given the transition of the urban industrial mix from manufacturing to services.

3.7 CONCLUSIONS

This paper has argued that the transition from an industrial to a post-industrial service-based economy can help explain current trends in density and deconcentration of metropolitan employment by demonstrating that identical increases in aggregate metropolitan employment originating from various productive sectors generate different urban density values. Namely, it shows that service sectors support relatively higher population and employment densities than manufacturing-related sectors. The paper also demonstrates that sector growth under optimality has the ability to spatially expand the city and possibly reduce population density giving caution to policies designed to restrict expansion. Commercial density (employees per commercial acre) increases with FIRE and high-wage services suggesting increased interaction of workers and that coveted production externalities such as knowledge spillovers may still exist though overall employment density may be decreasing, and that commercial density may be a more appropriate indicator of these effects. Regarding the effects of density, the research suggests that certain urban characteristics may benefit further econometric studies on density's relationship with productivity. Another key result is that local city finances are generally strained as cities lose manufacturing and gain service sectors.

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3.8 APPENDIX

Table 3.7: Export Expansion Specifics

	Manufacturing-Related Sectors			Service Sectors			
	Computer Manufacturing	Manufacturing	Wholesale	FIRE	High Services	Lodge	Retail
Own Sector Land	2.4	3.6	11.4	2.0	1.1	2.8	7.3
Indirect Land	0.1	0.6	(0.8)	(0.8)	(1.0)	0.2	(0.4)
Residential Land	21.9	17.9	13.8	10.3	13.0	5.2	9.0
Total Land	24.4	22.1	24.4	11.5	13.1	8.2	15.9
Change in Local CPI	0.03%	0.04%	0.03%	0.04%	0.04%	0.04%	0.06%
Real Income (millions) (Percent)	5.7 (0.35%)	4.1 (0.25%)	4.1 (0.25%)	3.6 (0.22%)	4.1 (0.25%)	1.9 (0.11%)	3.2 (0.19%)
In-Migrants	78	76	72	71	72	65	70
Population Change	123	123	115	113	114	104	111
Vacant Land Percentage	33.6%	34.2%	29.1%	60.5%	53.8%	78.3%	43.4%

Table 3.8: Capital Expansion Specifics

	Manufacturing-Related Sectors			Service Sectors			
	Computer Manufacturing	Manufacturing	Wholesale	FIRE	High Services	Lodge	Retail
Own Sector Land	1.5	2.0	8.6	1.3	0.3	2.8	2.4
Indirect Land	2.1	1.7	(0.002)	0.1	1.5	0.4	0.9
Residential Land	17.6	15.8	14.6	17.6	13.4	5.6	13.3
Total Land	21.2	19.5	23.2	19.0	15.2	8.8	16.6
Change in Local CPI	0.04%	0.03%	0.02%	(0.01%)	(0.06%)	0.03%	(0.07%)
Real Income (Percent)	5.1 (0.31%)	4.9 (0.30%)	4.2 (0.26%)	3.8 (0.23%)	3.9 (0.24%)	1.9 (0.12%)	3.8 (0.23%)
In-Migrants	76	75	73	73	75	66	74
Population Change	120	120	116	117	121	105	119
Vacant Land Percentage	35.0%	38.0%	31.0%	38.0%	49.2%	74.1%	44.4%

Table 3.8: Total Factor Productivity Expansion Specifics

	Manufacturing-Related Sectors			Service Sectors			
	Computer Manufacturing	Manufacturing	Wholesale	FIRE	High Services	Lodge	Retail
Own Sector Land	1.2	1.7	8.4	1.3	0.3	2.8	2.3
Indirect Land	2.0	1.7	0.1	0.1	1.4	0.4	0.9
Residential Land	16.6	15.1	14.5	17.1	13.4	5.6	13.2
Total Land	19.8	18.5	23.0	18.5	15.1	8.8	16.4
Change in Local CPI	0.04%	0.03%	0.02%	(0.01%)	(0.05%)	0.03%	(0.06%)
Real Income (Percent)	4.9 (0.30%)	4.7 (0.28%)	4.3 (0.26%)	3.8 (0.23%)	3.9 (0.24%)	1.9 (0.12%)	3.8 (0.23%)
In-Migrants	75	74	73	73	75	66	74
Population Change	119	118	117	116	121	106	119
Vacant Land Percentage	37.2%	39.5%	31.3%	39.0%	49.4%	74.1%	44.8%

4. SECTOR LAND USE AND OPTIMAL INDUSTRIAL MIX

4.1 INTRODUCTION

Industrial composition has been primarily analyzed in the explanatory sense, whether in explaining differences in city size or regional characteristics such as income inequality or employment growth rates.[17] From a local perspective, communities are approached by developers with projects consisting of one or more industrial sectors in which they can either accept or reject.[18] Local governments also use land use allocation programs to stimulate economic activity.[19] Industrial sectors have unique impacts on land use, tax revenue and household income, which affect the local economic environment and the welfare of existing residents. For example, while a high-wage, labor-intensive sector will increase resident household income, it will also increase the local population by attracting more in-migrants, which may lead to an increase in disamenities such as congestion. Sectors also generate different levels of tax revenue to local governments that impact the quality of local public services. Given the unique impacts of industrial sectors on the local community, it is reasonable to ask, what is the optimal development project for a community or city? Also, what is the optimal mix of industrial sectors for a given amount of land?

This paper uses a data-intensive computable general equilibrium (CGE) model with extensive sectoral and residential land data to estimate the impact of an individual sector's growth on the local environment from a land use perspective. It also evaluates the optimal combination of sectors for a proposed development project using a range of efficiency variables. The results provide a number of insights for policy makers. First, high-wage services, such as the medical, legal, computer, management and engineering

[17] Henderson (1974); Cloutier (1997); Garcia-Mila and McGuire (1993)
[18] Henderson (1991).
[19] McDonald (2001).

sectors, yield the largest increases in population and household income to a city, whereas Retail's modest indirect effects make it attractive to areas with limited available land. Second, individual sectors have unique land requirements (or land multipliers) that can be parsed into commercial and residential land to derive optimal zoning policies. Third, the results reveal *sector growth complements*: sectors that interact with each other to increase efficiency measures or city objectives. Finally, the results demonstrate the importance of traditional manufacturing to medium and small cities; however, if manufacturing is unavailable, export growth in retail or tourism can substitute and increase most efficiency or objective measures.

The paper proceeds as follows: Section 2 reviews industrial mix and local development in the literature. Section 3 describes the model and simulations. Section 4 presents the results. Section 5 provides sensitivity analysis and the last section concludes.

4.2 INDUSTRIAL MIX AND LOCAL DEVELOPMENT

A city's urban industrial mix has been used to explain city sizes. Building on the work of Edwin Mills (1967), Henderson (1974) uses a general equilibrium model to analyze equilibrium and optimum city sizes. He states that cities or population agglomerations form due to the existence of technological economies of scale found in production or consumption activities. The majority of work in agglomeration economies focuses on the economies of scale in production, though in more recent work, Gleaser and Gottlieb (2006) identify the possible agglomeration benefits in consumption. While Henderson focuses on cities producing the same good which give the same equilibrium and optimal size, he states that cities will differ in sizes because they produce different goods that are subject to different economies of scale. This suggests that cities which produce goods with greater economies of scale will result in larger city sizes. An extension of Henderson's work by Abdel-Rahman (1990), models the formation of a diversified city through economies of scale (cost-reductions) of shared inputs between different industries. He finds, as the city size increases, the more variety of intermediate inputs a city produces and the more specialized it becomes in its traded good. His model suggests that cities with different industrial mixes can and will result in different equilibrium sizes.

On the empirical relationship between industrial mix and city size, Henderson (1988, 1997) examines both the overall distribution in the size of cities, as well as the differences in industrial composition between medium size cities and large urban centers. A medium size city may loosely be defined by an urban population between 100,000 and 500,000. In terms of production diversity, Henderson finds that medium size cities have more standardized production and traditional items, whereas larger cities (over 500,000) have more experimental, evolving, and special order production. While manufacturing employment is distributed over both medium and large cities, its composition is different. Metro areas under 500,000 have larger employment shares in traditional manufacturing goods, such as textiles, food processing, and pulp and paper. If large metro areas do have manufacturing, it tends to be diverse, not specialized. Henderson states that larger metro areas are more service oriented and have more employment in finance, insurance, real estate (FIRE), publishing, apparel, and R&D activities. Medium-sized cities tend to be either local service centers (college, administrative centers providing retail, repair, transport and financial services to agriculture) or manufacturing centers specializing in the production of standardized items (auto, textiles, steel, food processing, pulp and paper, etc.) which they export. Large metro areas are more diverse in manufacturing featuring low physical output per worker, but high administrative and R&D activities and specialized in modern services (FIRE, advertising, consulting, etc.).

The other main research regarding the industrial mix of metropolitan areas examines its effect on regional characteristics such as income inequality and growth measures including population, gross city product, employment and wages. Bartik (1991a) finds that a shift towards high-wage industries has an ambiguous effect on income distribution as it improves for middle income households against the rich, but increases inequality between middle and low income households. Cloutier (1997) finds that the industrial mix of a city has a significant impact on income distribution and that the manufacturing and public sectors decrease income inequality, whereas high wage services increase inequality. Beeson and DeJong (2001) focus on national trends of population growth from 1840-1990 and find that the industrial mix of the city impacts population growth, stating that counties with larger percents of employment in commerce and manufacturing have had higher population growth rates.[20]

Garcia-Mila and McGuire (1993) analyze the industrial mix and long-term growth rates and find that the industrial mix of an economy helps to explain differences in the net growth rates of employment as well as the variability in employment across the states. They find that the state residual growth rates, which are similar to the competitive effects in shift-share analysis, are correlated with overall growth rates as well as with all

[20] They preface this by stating that the importance of industrial mix may just be a reflection of the rise of the manufacturing sector during this time and that counties with a larger share of manufacturing accrued larger benefits of population growth

industries in the economy. States with large concentrations of FIRE, construction and services had unexpectedly high employment growth, while states with larger employment levels in transportation, public utilities and manufacturing has unexpectedly lower growth. Economies with higher service employment tend to experience higher variability. Higher variability is also found in states with more mining, agriculture, fisheries and farming. They report that while many states focus development on manufacturing, that this may be "misguided" because services are growing at a faster rate and states with larger shares of fast-growing industries have had higher employment growth rates.

Expanding this research, Garcia-Mila and McGuire (1994) look at regional economic health in the eight U.S. census regions. The South and West regions had high employment growth during this period, but began with a smaller share of manufacturing and a larger share of services. While total earnings per capita declined over the period, this decline was not uniform across sectors, as some sectors experienced an increase in earnings per capita, and a region's earnings per capita was affected by its industrial mix. Thus, the industrial mix of a region is critical in evaluating the region's employment growth rates and earnings per worker over time.

In turning to literature on local development, Bartik (1991b) surveys the empirical literature and concludes that evaluating regional development policies are beneficial, though more work is needed to establish a base of empirical knowledge. In specifics to land allocation, Brueckner and Zenou (1999) determine that additional land allocated to industrial or commercial use leads to increased employment and land prices. McDonald (2001) develops microeconomic models to perform cost-benefit analysis on land use allocations between a generic industrial sector and residential use. He concludes that allocating land to industrial use is beneficial if it leads to less unemployment, an increase in land values, or if the increase in tax revenues offset additional costs.

4.3 MODEL SPECIFICS

The elasticities used in the model are taken from existing literature. Berck et al. (1996) provides an extensive literature survey on labor supply elasticities for differentiated household groups. They conclude labor supply elasticities range from 0.1 for low-income households to 0.8 for upper-income households, which are used in the model. Berck et al. suggests that women's labor supply may be more elastic; therefore, larger elasticities up to 2.3 were used in accordance with the findings of Rosen (1976). Larger elasticities increase the gross measures slightly and decreases efficiency measures slightly, but the overall results do not change.

As for land supply elasticities, Blackley (1999) used U.S. data to estimate long-run elasticities between 1.6 and 3.7. Malpezzi and Maclennan (2001) estimate supply elasticities post WWII between 6 and 13. Green, Malpezzi and Mayo (2005), using the model developed by Mayer and Somerville (2000), estimate metropolitan-specific supply elasticities for 45 cities ranging from –0.3 for Miami to 29.9 for Dallas. They find low elasticities when cities are geographically constrained, heavily regulated, have high population density or not growing. This paper uses 6.0 for land supply elasticities. As expected, lower elasticities increase the efficiency measures and larger elasticities decrease them, though neither changes the results of the paper.

Migration elasticities with respect to real income and unemployment are set in accordance with Schachter and Althaus (1989) with the in-migration real income elasticity set at 4.61 and the unemployment component set at –2.7. Renkow and Hoover (2000) estimate commuting elasticities with respect to wage range from 0.116 for rural-to-metro commuting and 0.257 for metro-to-metro commuting. The commuting elasticity in this paper is set at 0.2. These elasticities produce results consistent with Bartik (1993) that migrating workers fill around 75 percent of new jobs. Greenwood and Hunt (1984) analyze 57 labor markets and find that migrating workers fill between 20 and 80 percent of new jobs; therefore, smaller and larger migration elasticities are examined to account for this.

Land Specifics in the Model

A few notes should be mentioned regarding how land is handled in the model. The public use of land (streets, parks, etc.) is not modeled, though it is expected to increase with growth, the amount of land is primarily determined by policy. The model does not account for excess capacity or available vacant land in the city that may be substituted in place of new land. In other words, only commercial and residential land that is currently occupied is used in the model. The model does not use fixed lot size with respect to sectors or households; therefore, they can alter their consumption of land without changing lots. Public policy, different substitution elasticities with respect to vacant land among sectors and fixed lot size may alter the results of the paper.

4.4 SETTING UP THE SIMULATIONS

Before setting up the simulations in detail, it is important to describe each of the following sectors: Manufacturing, Computer Manufacturing, High Services, Retail, Wholesale, and Conference Tourism. Table 4.1 gives some descriptive characteristics of each sector save for Conference Tourism, which is described in detail below. The Manufacturing sector is land intensive. This sector engages in the production of clothes and furniture along with the publication of newspapers, periodicals, and books. Plastics, glass, concrete and metal products are also made in this sector. The Computer Manufacturing sector specializes in producing computers and the hardware associated with them such as computer storage devices and computer terminals. This sector also uses a large amount of land and has the highest average wages. Both of the manufacturing sectors essentially produce standardized products and are not the small, diverse, high R&D manufacturing found in large cities.[21] As mentioned, the High Services sector is primarily composed of legal, medical, business, architectural and engineering services. Retail is self-descriptive and includes car dealerships, grocery stores and shopping malls. Wholesale includes warehousing, lumber, distribution centers and equipment sales. Conference Tourism is comprised of expenditures in three sectors: Lodging, Restaurants and Retail. These conferences include business seminars for education and/or training purposes to conventions on a wide variety of topics. The average expenditure for each conference attendee is found in Table 4.2.

[21] See Henderson (1997)

Table 4.1: Description of Sectors

Sector	Computer Manufacturing	High Services	Manufacturing	Retail	Wholesale
Employment	3784	8459	6007	4208	2207
Percent of Total	5.9%	13.2%	9.3%	6.6%	3.4%
Average Wage	$60,500	$24,838	$24,880	$10,178	$28,357
Percent of HH Consumption	0.1%	13.1%	2.1%	18.4%	3.9%
Percent of Intermediate Demand	8.8%	7.6%	38.7%	0.8%	13.1%
Acres	145.8	51.8	232.7	130.0	151.3

Table 4.2: Conference Tourism Expenditures

Expenditure Category	Average Daily Expenditure	Percent of Expenditure
Lodging	$92.58	48.0%
Restaurants	$51.04	26.4%
Retail	$49.39	25.6%
Total	$193.01	100.0%

From the Fort Collins Convention and Visitors Bureau (FCVB)

The simulations follow two lines. The first analyzes the impact of each sector individually by increasing its land use. The second part assumes that the city is considering a development project consisting of 15 commercial acres. The development of the 15 acres is broken up into a lead sector, which uses 10 acres, and a supplemental sector, which uses 5 acres. Total land use, commercial land (including indirect effects) plus residential land, is assumed not to be a constraint; therefore, total land use may well exceed the 15 commercial acres. The variables of interest include total land use, new households to the area, total employment increase, total tax revenue generated and the increase in real household income. To help determine optimality, four efficiency or objective measures will be examined. They are tax revenue per additional acre, tax revenue per additional household, real household income per additional acre and real household income per additional household. The tax revenue measures provide proxies for the quality of city services and the real household income measures provide proxies for household welfare measures.

The technique to implement the increase in sector land use is to keep the structure of the sectors constant. That is, sectors employ average number of workers per acre and per capital expense. The idea is to provide "more of the same" type of sector to the urban landscape. To do so, these proportions remain constant, so as not to impose structural change in the sector by making it more or less labor- or capital-intensive. To maintain these proportions, a combination of two types of growth is used: export and capital migration or local growth. Export growth is demand-induced growth and has been evidenced across U.S. cities (Brown, Coulson and Engle [1992] and Nishiyama [1997]). This type of growth results in increased prices for factors of productions such as land and capital. Capital migration or local growth is supply driven and described by Engle (1979) as a migration of capital to a region. This type of growth lowers prices on capital resources in the economy. To maintain the original sector proportions for employees per acre and per capital expense, a combination of these two types of growth are used. This is shown technically for export growth by increasing PW0 in Equation (13) and for capital migration by increasing KS0 in equation (20).

To summarize, to increase the Retail sector by 1-acre, PW0 and KS0 are both increased until the land used by the Retail sector increases by 1 acre, while maintaining Retail's original employee/acre and employee/capital expense proportions. The same technique is used for all sectors individually and in combination with each other. For example, in the lead-supplemental expansions for say, Manufacturing—High Services, the 10 acre Manufacturing expansion and the 5 acre High Services expansion both maintain their original employee/acre and employee/building capital proportions through increasing both PW0 and KS0 in the equations above. In the Conference Tourism expansions, not only are the proportions held constant, but so are the relative percents of expenditures in the three included sectors.

4.5 SIMULATION RESULTS

Individual Sectors

The first results analyze the impact of land expansion in individual sectors. Table 3 provides a summary of 1-acre sector expansions. As the top of Table 4.3 shows, a 1-acre High Service expansion results in the largest total land use (14.6 acres) followed by Computer Manufacturing (12.1) with Retail yielding the least total land use at 2.0 acres. These values can be thought of as the sector's land multiplier. The land multipliers increase slightly as the expansions consume more acreage and more migrating households demand local goods causing the benefiting local sectors to expand, thereby increasing the indirect effects. This effect, however, is marginal. For example, the 1-acre Retail expansion has a land multiplier of 2.01, whereas a 10-acre Retail expansion has a land multiplier of 2.04. High Services also results in the largest increases in migrating households (37), employment (86) and real household income (3.64 million). Computer Manufacturing produces the largest total tax revenue values (0.25 million). Wholesale yields the smallest number of migrating households (4), employment gains (9), total tax revenue (0.02 million) and real household income (0.39 million).

Total land use comes from two sources: commercial and residential demand. The commercial demand for land comes from both the expanding sector as well as from other productive sectors that benefit from indirect effects of the initial expansion. Residential demand for land comes from migrating households and residential households. Due to

Table 4.3: Individual Sector Results for 1-Acre Sector Expansions

Sector	Manu-facturing	Computer Manuf	High Services	Retail	Whole-sale	Conference Tourism
Total Acres	7.5	12.1	14.6	2.0	2.6	2.1
Households	9	16	37	5	4	11
Employment	20	36	86	12	9	26
Tax Revenue (millions)	0.201	0.247	0.223	0.071	0.016	0.187
Household Income (millions)	1.299	2.213	3.641	0.402	0.387	0.592
Tax per Acre	$26,611	$20,426	$15,281	$35,487	$6,084	$87,744
Tax per Household	$21,454	$15,114	$6,036	$13,737	$4,092	$17,816
Income per Acre	$172,118	$182,765	$249,497	$199,897	$146,220	$277,537
Income per Household	$138,763	$135,231	$98,548	$77,382	$98,335	$56,354

the fact that the simulations are acre-based by sector, the primary difference in land use is due to change in residential demand of land. Using these two sources of land demand, the differences in total land use can be explained.

The High Services expansion uses the most total land primarily because of the increased residential land demand. It draws the greatest number migrating households, who demand residential land as well as goods and services from local sectors, such as Low Services (repair, cleaning, beauty services, etc.) and Restaurants, which in turn increase these sectors' land use. High Services also increases real household income by the largest amount, which allows existing households to consume more housing services and buy larger houses with more residential land. The reason behind the sector results are found in the production nature of the sectors. High Services is a labor-intensive sector that uses a small amount of land per employee. Therefore, a 1-acre High Services expansion demands more workers, which has two effects. First, it brings in more households and, second, raises wages more than other sectors, which helps to increase real household income. Both effects result in more residential land use. Computer Manufacturing, though land-intensive, pays the highest average annual wage, which increases household income. Retail, on the other hand, has the smallest land multiplier, as the 1-acre Retail expansion results in 2.0 acres of total land use. Retail is relatively land-intensive due to big-box retailers and pays low wages, which together suppresses household migration and increases crowding out as the Retail expansion must compete harder to lure workers away from other productive sectors. Conference Tourism, which includes the Retail sector, along with Lodging and Restaurants, which are both low-wage sectors, also yields a low land multiplier. The Wholesale sector also results in a small land multiplier at 2.6 acres, which is due to Wholesale's land intensiveness, without being labor-intensive, thereby drawing in the least number of migrating households.

In turning to the efficiency or objective measures in the bottom of Table 4.3, Conference Tourism generates the largest tax revenue per additional acre at $87,744 followed by Retail and Manufacturing. The highest tax revenue per additional household is generated by Manufacturing at $21,454 followed by Conference Tourism and Computer Manufacturing. Real household income per additional acre comes from

Conference Tourism at $277,537 followed by High Services. Real household income per additional household is generated by Manufacturing at $138,763 followed by Computer Manufacturing. Wholesale yields the lowest values in three of the four efficiency measures. The results demonstrate that the efficiency measures are maximized by different sectors and will be used to find the optimal industrial mix of an urban expansion under the second set of simulations.

Conference Tourism and Retail are sales tax intensive sectors, with small land multipliers, that result in large tax revenues per acre. Manufacturing and Computer Manufacturing, though generating tax revenue through property and use taxes, are not as labor intensive as Conference Tourism and Retail and result in higher tax revenue per household. The income per acre measure is intriguing as the low-wage sector of Conference Tourism yields the highest value. This is due to being labor-intensive with a small land multiplier. Retail also yields the third highest measure due to these effects. High Services generates the second highest measure as it is not land-intensive. Computer Manufacturing, while paying the highest average annual wages, is a land-intensive sector resulting in the fourth highest income per acre measure. Income per household is also intriguing as Manufacturing, not the high-wage sector of Computer Manufacturing, yields the largest value. This is due to Computer Manufacturing not causing as much crowding out and in its greater in-migrations of new households due to its lesser percentage of intermediate demand and higher wages. When combined with other sectors as a supplemental expansion, this mechanism works to increase income per household more than Manufacturing as will be discussed below.

Before moving to the second set of simulations, Table 4.4 gives zoning estimates for the acre expansions into commercial and residential classifications. For these zoning estimates, agriculture/ranch land is classified as undeveloped land. The results show that Retail, Wholesale and Conference Tourism increase the percentage of commercial land in the city. Manufacturing, Computer Manufacturing and High Services decreases the percentage of commercial land with High Services producing in the most extreme results. The causes behind these results are again found in the production nature of the sector. Computer Manufacturing pays the highest wages which allow residents to consume more residential land and High Services pays relatively high wages and is both labor-intensive and uses little commercial land.

Table 4.4:
Zoning Estimates: Commercial and Residential Land
(Results show a 1-acre expansion)

Sector	**Base Data**	Manu-facturing	Computer Manuf.	High Services	Retail	Whole-sale	Conference Tourism
Commercial	**22.9%**	14.7%	8.3%	3.1%	34.5%	32.5%	27.5%
Resident	**77.1%**	85.3%	91.7%	96.9%	65.5%	67.5%	72.5%

Optimal Industrial Mix

The industrial mix efficiency results are presented in Table 4.5. The results in this section typically, but not always, follow the individual results. For example, under the Manufacturing lead-sector expansions, the results show that supplementing this expansion with either 5 acres of Conference Tourism or Retail will generate more tax revenue per additional acre than additional 5 acres of Manufacturing. A full 15-acre Manufacturing expansion, though, yields the highest tax revenue and income per household. As for income per acre, this measure is individually maximized by a 15 acre expansion in Conference Tourism, but a supplemental expansion of High Services maximizes the measure under the lead-sector Manufacturing expansion. This is because the lead Manufacturing expansion causes crowding out in other productive sectors, when supplemented by Conference Tourism, the low-wage sectors of Lodging, Retail and Restaurants expand causing the crowding out shift to higher wage sectors such as High Services. When supplemented by High Services, the opposite result occurs and the crowding out shifts to lower wage sectors such as Lodging resulting in a larger income per acre value.

More generally, for all lead-sector expansions, a supplemental Conference Tourism expansion increases tax revenue per acre and a supplemental Manufacturing expansion increases tax revenue per household. Income per acre can be increased in all lead-sector expansions except High Services by a supplemental expansion of High Services. In the High Services lead-sector expansion, income per acre can be increased by Conference Tourism. The income per household measure follows a similar mechanism as income per acre. Income per household is maximized expansions, a supplemental expansion of Computer Manufacturing yields the largest values. For example, the Retail lead-sector expansion causes crowding out, the supplemental Manufacturing expansion shifts the crowding out to higher wage sectors such as High Services and Computer Manufacturing whereas a supplemental Computer Manufacturing expansion causes less crowding out of higher wage sectors such as High Services as it brings in more migrating households and it shifts the remaining crowding out from the

Table 4.5: Optimal Industrial Mix

* Maximized Value

Manufacturing (Manf)	Tax/Acre	Tax/HH	Income/Acre	Income/HH
15 Manf	$26,600	$21,081*	$172,174	$136,450*
Manf-CM	$23,809	$18,094	$176,441	$134,090
Manf-HS	$20,699	$10,739	$207,585*	$107,700
Manf-Retail	$27,539	$19,456	$175,077	$123,691
Manf-Wholesale	$23,688	$18,316	$168,465	$130,258
Manf-CFT	$33,938*	$19,739	$184,458	$107,285
Computer Manufacturing (CM)	Tax/Acre	Tax/HH	Income/Acre	Income/HH
15 CM	$20,282	$14,582	$181,706	$130,641
CM-Manf	$21,833	$16,070	$179,720	$132,284*
CM-HS	$18,220	$9,789	$204,847*	$110,057
CM-Retail	$21,442	$14,524	$183,186	$124,081
CM-Wholesale	$19,025	$13,647	$178,698	$128,185
CM-CFT	$25,660*	$15,293*	$189,202	$112,763
High Services (HS)	Tax/Acre	Tax/HH	Income/Acre	Income/HH
15 HS	$14,939	$5,671	$239,398	$90,879
HS - Manf	$17,221	$7,336*	$227,847	$97,063
HS - CM	$16,442	$7,226	$224,065	$98,469*
HS - Retail	$16,139	$6,215	$238,574	$91,872
HS - Wholesale	$14,334	$5,696	$234,621	$93,234
HS - CFT	$19,434*	$7,055	$242,331*	$87,965
Retail	Tax/Acre	Tax/HH	Income/Acre	Income/HH
15 Retail	$34,105	$13,284	$197,342	$76,865
Retail - Manf	$29,588	$17,135*	$181,798	$105,285
Retail - CM	$24,020	$14,283	$186,265	$110,755*
Reatil - HS	$19,080	$7,430	$233,545*	$90,950
Retail - Wholesale	$23,970	$11,008	$178,871	$82,145
Retail - CFT	$54,315*	$15,778	$226,723	$65,861
Wholesale	Tax/Acre	Tax/HH	Income/Acre	Income/HH
15 Wholesale	$6,111	$4,063	$146,835	$97,621
Wholesale - Manf	$18,432	$13,585*	$162,325	$119,639
Wholesale – CM	$16,182	$11,460	$171,736	$121,624*
Wholesale - HS	$12,821	$5,577	$219,648*	$95,539
Wholesale - Retail	$14,308	$7,900	$161,414	$89,125
Wholesale - CFT	$30,014*	$11,904	$184,467	$73,164

Conference Tourism (CFT)	Tax/Acre	Tax/HH	Income/Acre	Income/HH
15 CFT	$81,399*	$17,060	$264,941*	$55,528
CFT - Manf	$47,055	$18,455*	$206,573	$81,021
CFT – CM	$36,712	$16,095	$203,963	$89,420*
CFT – HS	$29,533	$9,659	$246,402	$80,589
CFT - Retail	$68,511	$16,701	$245,907	$59,947
CFT - Wholesale	$54,659	$15,266	$222,341	$62,098

high-wage sector of Computer Manufacturing to a high-wage sector of Computer Manufacturing to a relatively lower-wage sector such as Manufacturing.

The results show that if certain sectors are not available to maximize the desired efficiency measure, other sectors can substitute to increase the efficiency measure. For example, the results show that a supplemental expansion by any other sector save Wholesale in the 10-acre High Services lead-sector expansions will increase tax revenue per acre. The same type of result is seen in the 10-acre Wholesale lead-sector expansions as all other sectors in a supplemental role can increase tax revenue per acre, income per acre and tax revenue per household. Supplemental expansions in Manufacturing, Computer Manufacturing and High Services increase income per household. This result is important as manufacturing firms have been leaving areas of aggregated employment (Desmet and Fafchamps [2006]). The results also show the importance of traditional Manufacturing, as under a Wholesale lead-sector expansion, a supplemental Manufacturing expansion increases all four efficiency variables. A supplemental Manufacturing expansion also increases three of the four efficiency variable in the lead-sector expansions of Computer Manufacturing and High Services and two of the four efficiency variables in Retail and Conference Tourism expansions.

4.6 SENSITIVITY ANALYSIS

Different values for elasticities were demonstrated in the *Determining Key Elasticities* section above. This section considers the type of growth, namely, export growth. The simulations preformed in the paper are an extension of the current economy with consumption of the additional goods and services from the sector expansions coming from both local residents and consumers outside the economy. Many urban expansions target consumers outside the economy, especially Retail. The results in Table 4.6, for 1-acre sectoral expansions, present the efficiency measures under pure export growth meaning that the sectoral expansion is driven solely by export demand, which puts upward pressure on local prices. Technically, only PW0 in equation (13) is increased to induce the acre expansions.

Table 4.6: Export Growth Results for 1-Acre Expansions

Sector	Tax per Acre	Tax per Household	Income per Acre	Income per Household
Manufacturing	$28,940	$22,475	$184,958	$143,641
Computer Manufacturing	$20,122	$15,041	$182,579	$136,474
High Services	$16,220	$6,181	$262,336	$99,970
Retail	$242,345	$27,450	$528,202	$59,828
Wholesale	$5,884	$3,829	$149,162	$97,069
Conference Tourism	$153,310	$20,345	$374,047	$49,639

The overall results show that pure export growth generally increases all efficiency or objective measures for all sectors compared to the original simulations. The results show that the efficiency measures from the sectors that are export-oriented and sell primarily to consumer outside the economy such as Manufacturing, Computer

Manufacturing, Wholesale and Conference Tourism do not change much. High Services' values increase, but due to the higher wages it pays, it limits crowding out keeping values in check. The results for Retail, however, increase dramatically, save for income per household due to crowding out as Retail is 18.4% of local household expenditures. Tax revenue per acre increases from $35,487 to $242,345 per additional acre. Tax revenue per household increases by $13,713. Income per acre increases from $199,897 to the highest value at $528,202 far exceeding Conference Tourism's value of $374,047. While, these measures spike in value, the efficiency measure of income per household falls from $77,382 to $59,828. The results show that an export-oriented Retail expansion greatly exceeds the results of Manufacturing in tax revenue per acre, income per acre and in tax revenue per household. Conference Tourism also generates value comparable to Manufacturing, which suggests that given the difficulty attracting Manufacturing firms, as the economy transitions from a industrial to a post-industrial service-based economy, cities can substitute an export-driven Retail or Conference Tourism expansions as they exceed Manufacturing in multiple efficiency measures.

4.7 CONCLUSIONS

This research has analyzed sector land use and the optimization of the industrial mix for urban development. The results demonstrate that individual sectors have different total land requirements or land multipliers. The sectors also generate different magnitudes of real income for resident households and tax revenue for local government. While high-wage services generate the largest gain in real household income for residents, but also attract the most in-migration and land use per acre of sector expansion. Retail's modest indirect effects make it attractive to areas with limited available land.

With regards to optimal development, the results reveal *sector growth complements*: sectors that interact with each other to increase efficiency measures. Another important results shows the importance of traditional manufacturing to medium and small cities; however, if manufacturing is unavailable, export growth in retail or tourism can substitute and increase most efficiency measures.

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5. OPTIMAL CITY SIZE, PECUNIARY EXTERNALITIES AND THE URBAN INDUSRTIAL MIX

5.1 INTRODUCTION

The emergence of a conceptual optimal city size has received significant attention and has lead to an extensive literature on the subject. Optimal city size is a function of the benefits that arise as the city grows against the costs of a larger urban area. These benefits and costs are generally referred to as centripetal forces (forces that pull population) and centrifugal forces (forces that push population). According to urban systems theory, as a city grows in size, resource-saving economies benefit firms as cost-per-unit fall; however, with the increasing size, urban diseconomies also rise, increasing per unit costs. Urban systems theory treats these externalities as real externalities such as the positive localization or urbanization economies of labor pooling, labor matching, shared inputs and knowledge spillovers or the negative externalities of commuting costs, congestion and pollution. Urban systems models hypothesize an inverted U relationship of real income per worker against city size with optimal city size occurring at the peak; however, until the recent work of Au and Henderson (2006), this relationship of net urban agglomeration economies had not been empirically estimated.

Krugman (1991) highlighted the role pecuniary externalities can play when an inefficiency is present by demonstrating that pecuniary externalities, along with imperfect competition and increasing returns, can lead to the concentration of economic activity. Unlike real externalities, that directly affect the resources of a third party, pecuniary externalities operate though changes in relative prices[22]. For example, an increase in demand for a good by one consumer increases the price of that good; therefore, possibly reducing another's consumption of that good. The difference is that real externalities have welfare implications whereas pecuniary externalities do not. Pecuniary

[22] For a discussion of pecuniary externalities see Holcombe and Sobel (2001)

externalities, or wage and price effects, however, can have welfare impacts in the presence of an inefficiency.

Cities may be overpopulated due to amenity levels, coordination failure among individuals and urban structure, or the distribution of land rent.[23] Regarding the latter, non-resident landowners benefit from a larger city through increased land rent, but are not subject to the increasing diseconomies; therefore, do not restrict city size to achieve optimal city size. This inefficiency can be resolved through the assumption of common ownership or an equal redistribution of land rents to resident households[24]. If an equal distribution of land rent inside the city is not observed, an inefficiency is created, as households with larger land income benefit disproportionally from a larger city size.

This paper uses a data-intensive computable general equilibrium (CGE) model with extensive sector and residential land data to estimate optimal city size of a single city with pecuniary externalities given the inefficiency of an unequal distribution of land (and capital) rent to households inside the city. The results are able to estimate and inverted U relationship between real income per worker and city size, determine the degree of overpopulation and estimate the relative shifts due to changes in the industrial mix. They show that a relative increase in export growth for services leads to a larger city size compared to export growth in manufacturing, whereas total factor productivity growth in manufacturing shifted the distribution further to the right than productivity growth in services. Also, this type of analysis allows a closer examination of the structure within a single city at different sizes. The results show that the distribution of households shifts toward lower income households as the city decreases in size.

[23] See Duranton and Puga (2004) and Henderson and Au (2006)
[24] See Pines and Sadka (1986)

The paper proceeds as follows: Section 2 reviews urban agglomeration and optimal city size in the literature as well as sets the intuition for the results. Section 3 describes the model and simulations. Section 4 presents the results for the original city. Section 5 analyzes changes in the urban industrial mix and the last section concludes.

5.2 URBAN AGGLOMERATION, CITY SIZE AND PECUNIARY EXTERNALITIES

The discussion of optimal city size begins with a discussion of urban agglomeration. Two main theories have emerged to explain the concentration of economic activity: the urban systems theory and the new economic geography. The urban systems approach finds its origins in Henderson (1974), who models technological economies of scale in production (or theoretically in consumption) that increase with city size.[25] Specifically, they are increasing returns in production that are external to the firm (meaning the firm produces under constant returns), but internal to the industry. The benefits are offset by rising commuting costs as the city expands spatially and average distance and congestion to the central business district (CBD) increase. Namely, as employment increases in the city, it results in higher average commuting costs for all residents.[26] These two forces interact to determine optimal city size defined as the maximum utility or welfare of participants in the economy. Cities vary in size due to differences in scale economies that arise from the unique industrial composition of a particular city.[27] The urban systems approach is extensively developed in the more comprehensive works of Henderson (1977, 1988).

[25] Henderson (1974) acknowledges drawing from Mills (1967).
[26] Attributed to Buchanan and Goetz (1972): "Efficiency Limits of Fiscal Mobility" Journal of Public Economics
[27] See Henderson (1988, 1997) for a more complete discussion.

While many have contributed this approach, some of the most important contributions have come from Abdel-Rahman (1988, 1990a, 1990b), who expands the approach to account for the role of consumption in agglomeration and monopolistic competition in production via product variety and differentiation as well as expanding into including the effects of urbanization economies—externalities that are external to the industry but internal to the city. Attempting to move away from the pure external economy model, Abdel-Rahman and Fujita (1990) demonstrate that a monopolistic competition model can parallel an external economy model.

In another attempt to move away from the pure external economy model for urban agglomeration, Krugman (1991) introduces the new economic geography and highlights the role that pecuniary externalities can play when an inefficiency is present. Pecuniary, or distributional, externalities operate through changes in relative prices via market interactions such as demand or supply linkages. Krugman focuses on pecuniary externalities associated with economies of scale and transportation costs that operate through forward and backward linkages in a two-region two-sector model. Given consumption's share of manufacturing, the degree of scale economies and transportation costs, concentrations of economic activity may form and feed on themselves through market linkages. This has been referred to as "circular causation" (Myrdal 1957) or "positive feedbacks" (Arthur 1990) leading to a core-periphery pattern of economic activity.

In a related paper, Krugman (1995) focuses on the connection between the new economic geography and city size. Diseconomies arise as workers demand land for residential purposes leading to an increase in land rent and commuting costs, thus net wage decreases with city size. The agglomeration benefits arise with economies of scale manifesting through imperfect competition. As Krugman states, the scale effects technically appear in product variety rather than production that increase with city size. The inclusion of iceberg transportation costs generates positive agglomeration forces. The competing centrifugal and centripetal forces determine city size.

Narrowing the focus from urban agglomeration to optimal city size, a large amount of literature hypothesizes an inverted U relationship between real income per worker and city size (Henderson 1974, Helsley and Strange 1990, Black and Henderson 1999, Fujita, Krugman and Venables 1999 and Duranton and Puga 2001). Until the recent work of Au and Henderson (2006), the postulated relationship remained theoretical. The reason being that under a system of free labor mobility and a stability condition, cities will be at the peak of this relationship or to some degree overpopulated leaving no cities to the left of the peak.

Overpopulation can be the result of amenity levels, as cities with higher amenities, all else equal, will tend to draw more residents and be to the right of their peak (Au and Henderson 2006). Cities can also be overpopulated due to coordination failure or urban structure (the distribution of land rent) (Duranton and Puga 2004). Overpopulation due to coordination failure can be resolved competition among private profit-maximizing land developers who internalize the external economies (Henderson 1985) or through autonomous local governments (Becker and Henderson 2000). Overpopulated cities may also be the result of non-resident landlords, who benefit from the increased land rent as the city grows, but who are not subject to the increasing diseconomies. This can be corrected through common ownership or an equal redistribution of land rents to resident households (Pines and Sadka 1986). Thus, inefficiency arises when common ownership inside the city is not observed. In the model, as will be seen, household groups receive disproportionate land and capital, and this inefficiency is used to help estimate an inverted U relationship between real income per worker and city size.

This paper begins with an existing city and is not interested in its formation, but rather its size. Since the paper is focused on a single city, the question of city type and urban hierarchy is not addressed, rather the paper attempts to estimate an inverted U relationship between real income per worker and city size of a single city with pecuniary externalities given the inefficiency of an unequal distribution of land and capital rent to households inside the city.[28] This is accomplished by uses a data-intensive computable general equilibrium (CGE) model with extensive land data that is able to capture the change in land and capital rent as city size changes. The model is non-spatial, and though land is used in both the commercial production of goods and services and in housing services for residential use, there are no transportation costs in the model. Without formally setting up the method used in the paper, the basic idea is to alter population in the city in order to estimate the relationship between real income per worker and city size measured in total resident employment.

In this framework, there are three perspectives that capture the tension of city size in pecuniary terms: the production, consumption and real income perspective. First, as the city size is reduced and workers leave the city, wages rise as labor supply curves shift. This affects resident firms in two ways. First, the direct impact is that a firm must pay higher wages as less labor is supplied, and second, the indirect impact is higher

[28] For a discussion on city type and hierarchy see Kolko (1999) and Black and Henderson (2003).

intermediate input prices as all resident firms must pay higher wages. However, there is less demand for land and capital in the city as output falls; therefore, firms pay lower rents. The consumption perspective follows the same logic. The model predicts that local prices for goods and services increase as the city decreases in size given the production effect and negatively affect all residents; however, they face lower rent for residential land consumption. Regarding the real income effect, local residents collect income from wages and rents on land and capital that are locally owned. All else equal, as wages increase so does real income; however, firms decrease production demanding less land and capital which lower real income to residents. The opposite effects occur as workers enter the city or as city size expands. This paper focuses on the change in local prices and the change in real income per worker as the city changes in size.

5.3 MODEL SPECIFICS

The elasticities used in the model are taken from existing literature. Blundell and MaCurdy's (1999) comprehensive review of empirical studies primarily from the 1970s and 1980s and report median labor supply elasticities with respect to wage of 0.08 for men and 0.78 for married women. Similar results were found in the literature summaries of Jacobsen (1998) and Filer, Hamermesh and Rees (1996). More recent work has found that women's wage elasticities have decreased (Blau and Khan 2007) and are becoming similar to men's as predicted by Goldin (1990). Blundell et al. (2007) estimate collective labor supply elasticities with U.K. data and find labor supply wage elasticity of women of 0.3. This paper uses 0.2 for labor supply wage elasticities. Larger labor elasticities decrease optimal city size. As employment is reduced and wages rise, resident households supply more labor suppressing the magnitude of the increase in wages and real income per worker.

As for land supply elasticities, Blackley (1999) used U.S. data to estimate long-run elasticities between 1.6 and 3.7. Malpezzi and Maclennan (2001) estimate supply elasticities post WWII between 6 and 13. Green, Malpezzi and Mayo (2005), using the model developed by Mayer and Somerville (2000) estimate metropolitan-specific supply elasticities for 45 cities ranging from –0.3 for Miami to 29.9 for Dallas. They find that cities that are geographically constrained, heavily regulated, high population density or not growing result in lower elasticities and vice versa. This paper uses 6.0 for land supply elasticities. Differences in land elasticities have a negligible effect on the results with smaller elasticities slightly decreasing optimal size.

Migration elasticities with respect to real income and unemployment are set in accordance with Schachter and Althaus (1989) with the in-migration real income elasticity set at 4.61 and the unemployment component set at –2.7. Renkow and Hoover (2000) estimate commuting elasticities with respect to wage range from 0.116 for rural-to-metro commuting and 0.257 for metro-to-metro commuting. The commuting elasticity in this paper is set at 0.2. These elasticities produce results consistent with Bartik (1993) that migrating workers fill around 75 percent of new jobs. Greenwood and Hunt (1984) analyze 57 labor markets and find that migrating workers fill between 20 and 80 percent of new jobs; therefore, smaller and larger migration elasticities are examined to account for this. Smaller migration elasticities lead to a lower optimal city size (or higher degree of overpopulation) and a higher real income per worker.

5.4 SETTING UP THE SIMULATIONS

The objective of the paper is to alter the size of the city in order to map out the inverted U relationship between real income per worker and city size. Labor is supplied in the model by resident households, commuting patterns and migration behavior. Commuting and migration are a function of their base value and relative changes in wage and real income respectively. Thus, city size, measured in resident labor, is embedded in the number of resident households; therefore, to alter city size, the number of resident households must change. This is accomplished in the model by changing what is labeled as the Natural Rate of Population Growth (NRPG) in equation (8) or the number of resident households in the model. Recall that there are three labor groups that are supplied by six household groups in the model. The logic is to reduce the size of the city without imposing changes on its structure. Any change in structure, will be determined by the optimizing behavior of firms and households. In order to decrease the number of resident households without imposing structural change to the city, the NRPG is lowered across all household groups. For example, The NRPG is initially set at 1, when NRPG is lowered to 0.9; this reduces the number of households in each household group by 10% keeping the initial distribution of households constant. This does not guarantee that the distribution will remain the same; in fact, it will not, as a reduction in the number of households change relative relationships in the model. Agents in the model are subject to profit and utility maximization, thus changes to the distribution are a function of agents meeting these optimality conditions. To summarize the method, the NRPG is altered to change the number of resident households in the model. The agents in the model are then free to maximize profit and utility by changing commuting or migration patterns.

5.5 SIMULATION RESULTS

Table 5.1 presents the results for real income per worker and city size measure in total employment. Figure 5.1 provides an illustration of these results. The base value for total employment in the model is 64,282 workers. The results demonstrate an inverted U relationship with maximum real income per worker at 52,711 workers. This suggests the city is overpopulated by 11,571 workers. As mentioned, a city can be overpopulated due to coordination failure, the degree of foreign land and capital ownership, or greater amenity levels compared to other cities of the same type. The first reason requires more data than this paper and model contain, while the second reason can be addressed. The data used to build the model reveals that 40.7% of land income and 56.8% of capital income leaves the economy due to foreign ownership such as national chains. Also, Fort Collins is consistently ranked as one of the best places to live suggesting a high level of amenities.[29] These qualities can help explain the degree of overpopulation in the city.

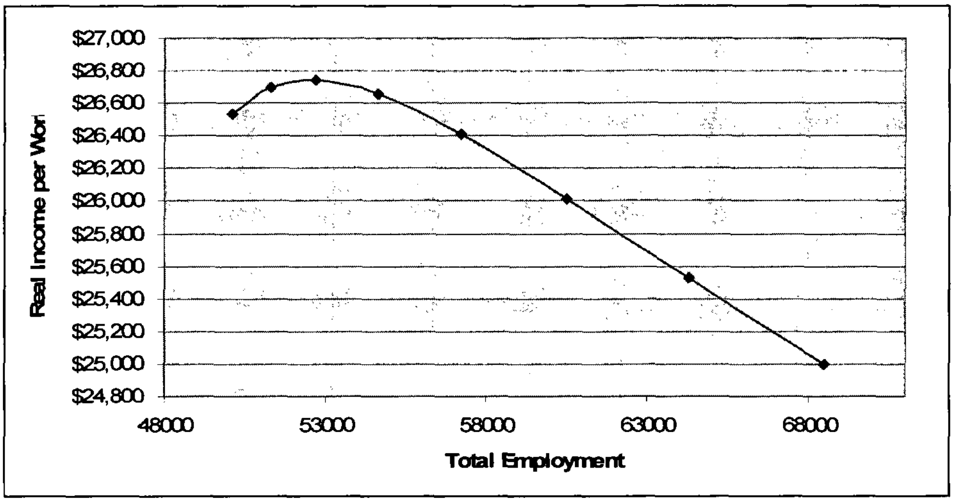
Table 5.1: Real Income per Worker and City Size

Total Employment	Real Income Per Worker
68,477	$ 24,999
64,282 (Base)	*$ 25,527*
60,469	$ 26,017
57,212	$ 26,413
54,634	$ 26,659
52,711*	$ 26,742*
51,306	$ 26,695
50,115	$ 26,537

* Estimated Optimal City Size

[29] See Cutler and Davies 2007. Recently, Fort Collins was ranked as the best place to live by Money magazine 2007.

Figure 1: Real Income per Worker and City Size



The next step is to explain the reasons behind the results in Table 5.1. As mentioned, there are three perspectives that arise as the city size changes. The production and consumption perspectives can be summed up by changes in the local price level. As employment changes, the local CPI can either increase or decrease depending on changes in the price of goods and services and the price of land or housing services as a reduction in labor increases wage, but decreases land and capital rent. Table 5.2 gives three perspectives on the local price level for all six household groups: the overall CPI, the goods and services CPI and the housing CPI.

As the city expands in size, local CPI increases across all household groups meaning that the rise in land rents overwhelm the benefits of lower wages to firms. This is seen when the local CPI is broken up into the goods and services CPI and housing CPI. While goods and services CPI decreases as the decrease in wages overwhelms the increase in rent for firms, the housing CPI increases reflecting higher rents for resident households. In other words, goods and services are relatively cheaper for resident households, but housing is relatively more expensive with the rise in housing greater than the decrease in goods and services.

The opposite effects occur initially as the city reduces in size; however, they do not remain as the city continues to decrease in size. At 54,634 workers, the local overall CPI for HH1 increases to 1.000, as the goods and services CPI continues to increase and the housing CPI begins to rise slightly. As the city continues to decrease in size, the overall CPI increases for HH1. At 52,711, HH2 experiences the same condition. This is also the peak of real income per worker. After this level of total employment, the overall CPI for HH3 increases past 1.000. The other household groups, HH4-HH6 continue to decline in the table.

The reason for the differences in households has to do with the stake they have in the local economy or the distribution of locally owned land and capital. The larger the ownership in the local economy the greater impact that changes in land and capital rent has on a household. Namely, as the city decreases in size, land and capital rents decrease as production and residential land demand fall affecting the households with the greatest ownership.

Table 5.3 illustrates that higher income households own the majority of the locally owned land and capital as these households are local business owners and/or demand larger houses with more residential land compared to lower income households. Therefore, as the city decreases in size, the real income of upper income households is more negatively affected compared to lower income households, who have relatively small shares of locally owned land and capital.

Table 5.2: Changes in Local Price Level

	Total Employment							
Total CPI	68477	64282 (Base)	60469	57212	54634	52711	51306	50115
HH1	0.002%	-	(0.002%)	(0.002%)	-	0.005%	0.011%	0.019%
HH2	0.003%	-	(0.002%)	(0.003%)	(0.002%)	0.001%	0.006%	0.012%
HH3	0.002%	-	(0.002%)	(0.003%)	(0.003%)	(0.001%)	0.002%	0.005%
HH4	0.002%	-	(0.002%)	(0.004%)	(0.006%)	(0.007%)	(0.009%)	(0.010%)
HH5	0.002%	-	(0.003%)	(0.006%)	(0.009%)	(0.012%)	(0.015%)	(0.019%)
HH6	0.002%	-	(0.003%)	(0.006%)	(0.010%)	(0.014%)	(0.018%)	(0.023%)
Goods and Service CPI	68477	64282 (Base)	60469	57212	54634	52711	51306	50115
HH1	(0.004%)	-	0.004%	0.007%	0.010%	0.012%	0.014%	0.016%
HH2	(0.003%)	-	0.003%	0.005%	0.007%	0.009%	0.010%	0.011%
HH3	(0.003%)	-	0.003%	0.006%	0.008%	0.010%	0.011%	0.013%
HH4	(0.003%)	-	0.003%	0.006%	0.008%	0.009%	0.011%	0.012%
HH5	(0.003%)	-	0.003%	0.006%	0.008%	0.010%	0.011%	0.012%
HH6	(0.003%)	-	0.003%	0.006%	0.009%	0.010%	0.012%	0.013%
House CPI	68477	64282 (Base)	60469	57212	54634	52711	51306	50115
HH1	0.017%	-	(0.014%)	(0.022%)	(0.021%)	(0.011%)	0.005%	0.028%
HH2	0.017%	-	(0.015%)	(0.024%)	(0.024%)	(0.017%)	(0.004%)	0.014%
HH3	0.017%	-	(0.015%)	(0.026%)	(0.031%)	(0.029%)	(0.023%)	(0.014%)
HH4	0.018%	-	(0.017%)	(0.032%)	(0.044%)	(0.054%)	(0.061%)	(0.068%)
HH5	0.020%	-	(0.019%)	(0.038%)	(0.055%)	(0.072%)	(0.086%)	(1.111%)
HH6	0.021%	-	(0.021%)	(0.042%)	(0.063%)	(0.083%)	(1.111%)	(1.120%)

Table 5.3: Land and Capital Income

	Total Number of Households	Land and Capital Income (millions)	Percent of Total	Land and Capital Income per Household
HH1	3491	4.87	1.3%	$1,396
HH2	5197	9.12	2.5%	$1,755
HH3	8972	62.15	16.6%	$6,927
HH4	2981	26.64	7.1%	$8,936
HH5	8595	92.95	24.8%	$10,815
HH6	10883	179.01	47.7%	$16,449

Recall that the simulations reduce resident households by the same percentage across all household groups in order to keep the structure of the city the same. Any change in structure or distribution of resident households would be a result of profit and utility optimization decisions. Thus, as the city decreases in size, land and capital income fall as less production occurs and less residential land is demanded. This adversely affects upper income households, but on the other side, wages increase benefiting all households. Household migration patterns are a function of real income and local unemployment (see equation 8). Thus, as city size decreases, high income households migrate out as their real income falls to a greater degree than low income households whereas low income households begin to see their real income rise as wages increase causing an influx of low income households to move into the city. This causes the distribution of resident households to change as city size changes. Namely, as the city decreases in size, low income households become a larger part of the distribution. The opposite also holds, as the city increases in size, higher income households are a larger percentage of the distribution. This is shown in Table 5.4.

Table 5.4: Distribution of Households

Total Employment	68477	*64282 (Base)*	60469	57212	54634	52711	51306	50115
HH1	8.6%	*8.7%*	8.9%	9.5%	10.9%	13.3%	16.6%	20.9%
HH2	12.9%	*13.0%*	13.0%	13.1%	13.1%	12.9%	12.3%	11.5%
HH3	22.3%	*22.4%*	22.6%	23.0%	23.5%	24.0%	24.4%	24.6%
HH4	7.4%	*7.4%*	7.4%	7.3%	7.1%	6.8%	6.5%	6.1%
HH5	21.5%	*21.4%*	21.3%	20.9%	20.3%	19.4%	18.4%	17.1%
HH6	27.3%	*27.1%*	26.8%	26.2%	25.1%	23.6%	21.8%	19.8%
Total Households	43462	*40119*	37085	34542	32644	31392	30644	30183

Therefore, the reason behind the inverted U relationship between real income per worker and city size is due to the changing distribution of households provided by the inefficient or unequal distribution of land and capital rent to households inside the city. As the city decreases in size, the wage effect overcomes the land and capital effects on real income for low income households causing real income for this group to rise. This draws more low income households to the city. At the same time, for high income households, who have a larger stake in the local economy through land and capital ownership, the loss of real income from land and capital, overwhelm the gains in wages causing greater loss in real income as the city decrease in size. This leads to larger out migration of high income households. This pattern is demonstrated by the change in the local price level presented in Table 5.2. As real income rises for low income households, more migrate to the area causing the housing CPI to increase and the overall CPI for these groups to increase. This dampens real income. So in sum, both the change in distribution toward low income households along with the price effects due to the inefficient or unequal distribution of land and capital rent to households inside the city give us an inverted U relationship between real income per worker and city size measure in total employment.

Population Density

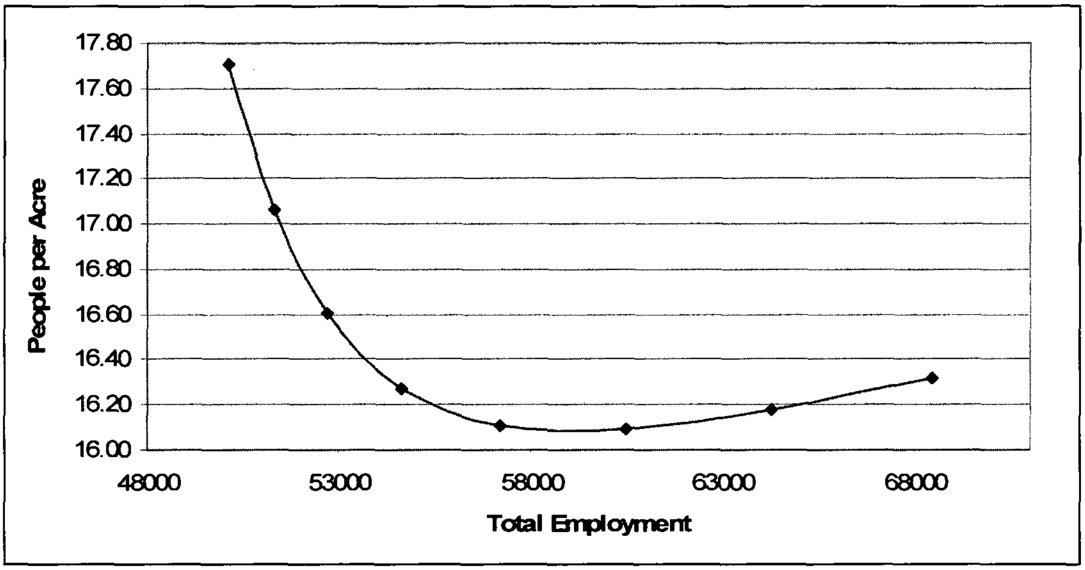
There is another urban characteristic of interest as city size decreases: population density. As the model includes both commercial and residential land, population density can be calculated. Recall, however, the way land is used in the model. Public land for streets, parks, etc. are not modeled, and neither is vacant land or fixed lot size. All land in the model is occupied by either commercial or residential use. Agricultural land is modeled, but not used to calculate density results.

There are two cases in presenting changes in population density. The first case, Case A, holds the amount of commercial and residential land constant as the city decreases in size. The logic of this case is that this land is still within city boundaries. As the city expands, land use can increase. Naturally, this leads to a decrease in population density as the city decreases in size as there are less residents over the same area. As the city increases in size, land use increases as well as population density. A second case, Case B, measures only occupied land as the city decreases in size and allows total land use of the city to decrease. In this case, population density begins to fall as the city decreases in size, but rises sharply after some threshold. The population results are presented in Table 5.5 and the results for Case B are illustrated in Figure 5.2. The reason is due to the change in the distribution of households away from high income households, who consume large houses and large amounts of residential land to low income households who consume relatively small houses or apartments in which residential land use is substantially less. This predicts that as the city grows, population density declines at first until it crosses a threshold in which it begins to increase as the city continues to grow.

Table 5.5: Population Density and City Size

Total Employment	Population Density (Case A)	Population Density (Case B)
68477	16.32	16.32
64282	16.18	16.18
60469	14.94	16.09
57212	13.86	16.11
54634	13.00	16.27
52711	12.35	16.60
51306	11.87	17.06

Figure 5.2: Population Density and City Size (Case B)



5.6 OPTIMAL CITY SIZE AND INDUSTRIAL COMPOSITION

Urban systems theory states that the urban industrial mix is a key element in determining optimal city size. Kolko (1999) finds the level of business services and manufacturing employment differs significantly by city size. As city size increases, business services maintain a larger share of employment and the manufacturing to business service ratio declines as city size increases. Kolko (1999) defines business services by the SIC codes 60-60 (FIRE) and 70-89 (Services). They cater primarily to other businesses, not households. They do not include wholesale, retail or consumer services such as medical, dry cleaning and education, though they do include advertising, consulting and janitorial services. Au and Henderson (2006) use this manufacturing to service ratio to categorize cities into types within the urban hierarchy. They state that, as the ratio increases, the inverted U shifts to the right, indicating a larger optimal city size.

Henderson (1988, 1997) and Black and Henderson (2003) describe the changes to the industrial composition of cities as they differ in size and move up the urban hierarchy. Some of the main differences are in the types of manufacturing and services that cities have. Henderson (1997) finds that small and medium cities are more specialized with manufacturing sectors that have standardized production with high physical output per worker. Larger cities have more diverse manufacturing with low output per worker and more R&D activities. The types of services also differ. Small and medium cities are local repair and retail centers or college towns whereas larger cities contain more modern services such as advertising, consulting, the arts and FIRE, who export these services to other areas.

In this section, differences in the industrial mix are considered. To analyze the changing industrial mix, another round of simulations is performed. The idea behind the simulations will be to simulate growth in different sectors within the city until total city employment expands by an identical amount. Thus, after the simulations, the city will be the same size, though the relative industrial mix will vary. The simulations will increase total employment in the city by 500 workers; therefore, the base employment of the city will increase from 64282 to 64782 workers. The sectors that will be used are Manufacturing, Computer Manufacturing, High Services, FIRE and Retail. Most of the sectors are self-descriptive; however, Computer Manufacturing is high-wage manufacturing and High Services are high-wage services such as medical, legal, engineering, consulting and computer services. Table 5.6 gives a description of the sectors. Recall that the data used in the model is from Fort Collins, Colorado, thus this is a small to medium size city whose description fits Henderson (1997).

Table 5.6: Description of Sectors

	Manufacturing	Computer Manufacturing	High Services	FIRE	Retail
Employment (Percent of Total)	6007 (9.3%)	3784 (5.9%)	8459 (13.2%)	2078 (3.2%)	4208 (6.6%)
Average Wage	\$24,880	\$60,500	\$24,838	\$16,714	\$10,178
Percent of Household Consumption	2.5%	0.1%	17.7%	12.3%	24.8%
Percent of Intermediate Demand	38.7%	8.8%	7.6%	6.2%	0.8%

Sector growth can be analyzed by three main processes: export growth, total factor productivity and capital migration or local growth.[30] Growth through exports results from an increase in external demand that shifts out the sector's demand curve. The sector increases its factors of production including land and labor in order to meet increased demand with increased production. This type of growth puts upward pressure on prices. To implement export growth, PW0 in equation (22) is increased for a specific sector. Productivity changes can be divided into total factor productivity (TFP), and the marginal productivity of labor or capital (MPL or MPK respectively) of which TFP dominates.[31] Cutler and Davies (2008) examine specific impacts of each type of productivity growth and conclude that TFP results in four times as much economic growth and that increases

[30] See Burnett, Cutler and Davies (2009) for a discussion.
[31] Prescott (1998) and Klenow and Rodriguez-Clare (1997) are recent examples.

in MPL or MPK primarily results in a reallocation of resources and limited economic growth. Since this paper is interested in sector-specific growth, TFP is used to simulate productivity growth. This is accomplished similar to Jones (2000) in that $DELTA_I$ in equation (2) in increased. The third type of growth is an increase in local supply or migration of capital to a region. Capital migration or local growth occurs when there is an increase in the supply of capital into the city through either local residents obtaining capital via branch banking, external firms move into town to take advantage of local demand or as a result of firm location decisions. The increase of sector-specific capital reduces the price of capital and shifts out the sector's supply curve increasing the sector's demand for land and labor as output increases. Local growth is implemented by increasing KS0 in equation (12).

An example of a simulation would be to increase PWO for the Manufacturing sector until total city employment increases by 500 workers. Next, PWO would be increased for the FIRE sector until total city employment increases by 500 workers; therefore the city is the same size in both simulations, but the city in the first simulation has relatively more Manufacturing and the second has relatively more of the FIRE sector.

Simulation Results for Industrial Composition

Table 5.7 provides the estimated optimal city size and degree of overpopulation for the sector simulations. Recall that city size for all simulations is identical (64782 workers). The difference is the industrial mix. For the export growth simulations, the results show that a city with relatively more Retail, FIRE or High Services results in a larger city size than a city with more Manufacturing or Computer Manufacturing. This result is in-line with economic theory, in that as the manufacturing to business services ratio decreases, the inverted U relationship shifts further to the right.

The TFP simulations have a different effect. The High Services expansion leads to the largest optimal city size followed by Manufacturing and Computer Manufacturing. While this case appears to conflict economic theory, recall that the type of manufacturing differs from small and medium size cities compared to large cities. Manufacturing in larger cities are more R&D oriented compared to small and medium cities. This result may reflect this difference as advances in R&D are reflected in TFP growth. As the Computer Manufacturing and Manufacturing become more R&D oriented, city size shifts further right.

The capital simulations lie between the export and TFP simulations for most sectors. They result in larger values for Manufacturing than export growth, but lower than TFP growth. For FIRE and Retail, the value is larger than TPF growth, but smaller than export growth. Capital growth for Computer Manufacturing results in the lowest optimal city size of the three types of growth for this sector. These growth results are further illustrated in Figures 5.3, 5.4 and 5.5.

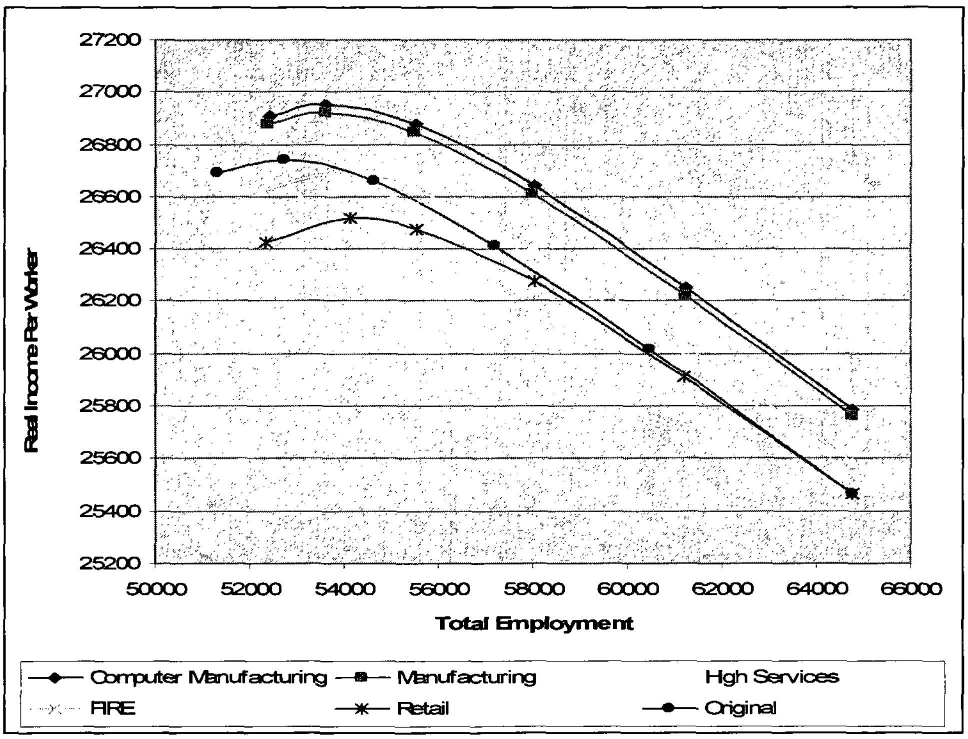
Table 5.7: Optimal City Size and Overpopulation Relative to Sector Expansion

	Export Growth		TFP Growth		Capital Growth	
	Optimal City Size	Degree of Over-population	Optimal City Size	Degree of Over-population	Optimal City Size	Degree of Over-population
Computer Manufacturing	53635	11147	53644	11139	53625	11157
Manufacturing	53611	11171	53684	11097	53676	11105
High Services	53753	11029	53880	10903	*	*
FIRE	53817	10965	53570	11212	53615	11167
Retail	54114	10668	53521	11260	53552	11230

* The High Services Capital Growth Simulation is Not Feasible

Figures 5.3, 5.4, 5.5 demonstrate that all growth shifts the inverted U to the right.[32] The original distribution is included and the city size is expanded by 500 workers through increasing NRPG in equation (8). While growth in any of the sectors increases real income per worker compared to the original, the Computer Manufacturing and Manufacturing shift the peak up while FIRE, High Services and Retail shift the peak down compared to the original relationship. The difference is that manufacturing sectors are primarily export sectors, while High Services, FIRE and Retail cater to local household demand (see Table 5.6).

Figure 5.3: Export Growth



[32] The data for Figures 3, 4 and 5 are provided in the Appendix.

Figure 5.4: Total Factor Productivity (TFP) Growth

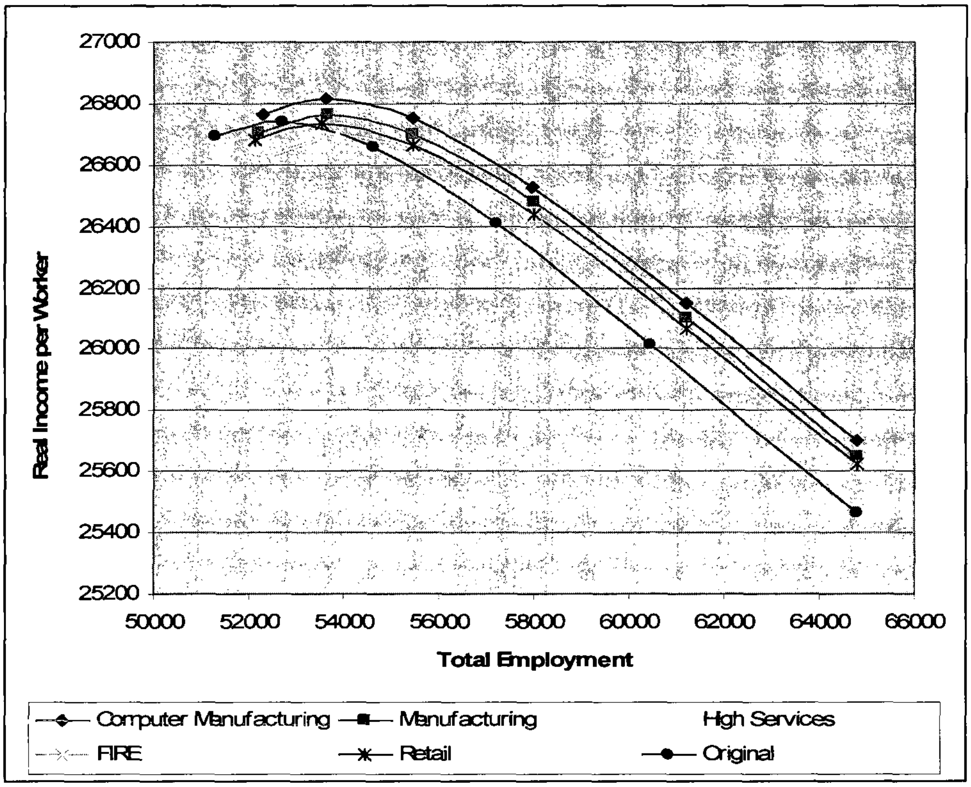
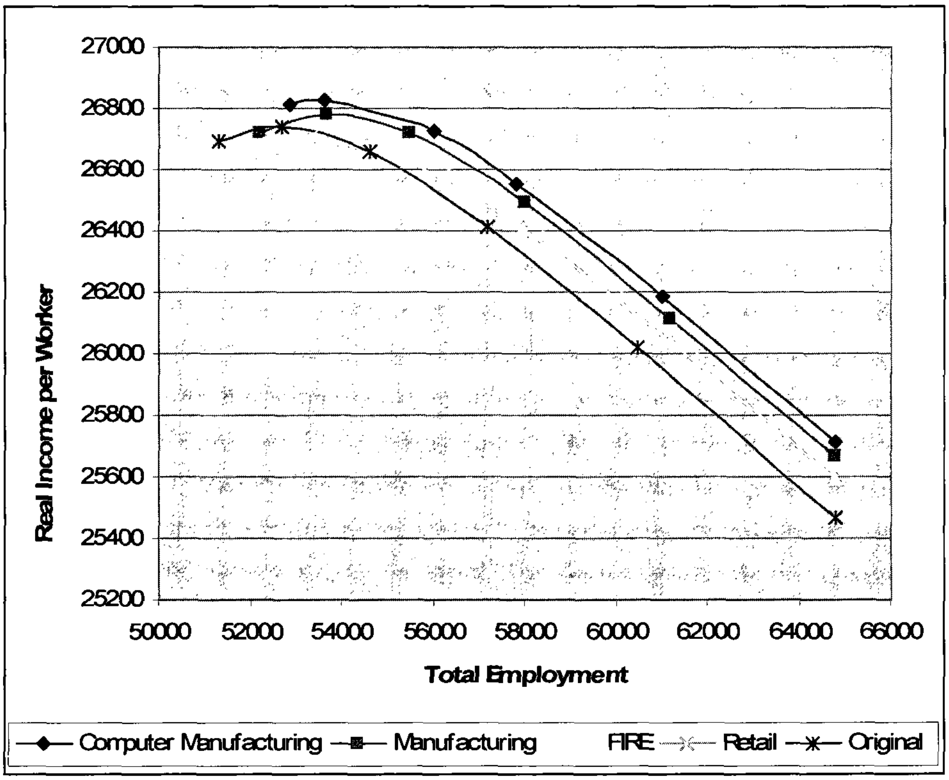


Figure 5.5: Capital Growth



5.7 CONCLUSION

This paper estimates an inverted U-shaped relationship of real income per worker and city size for a single city in a data-intensive computable general equilibrium framework with extensive land data. The relationship is estimated with pecuniary externalities due to the inefficiency provided by an unequal distribution of land and capital rent inside the city. This leads to a change in the distribution of households as city size changes. The results are able to determine the degree of overpopulation and estimate relative shifts due to changes in the industrial mix. They show that a relative increase in export growth for services leads to a larger city size compared to export growth in manufacturing, whereas total factor productivity growth in manufacturing shifted the distribution further to the right than productivity growth in services.

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5.9 APPENDIX

Table 5.8: Export Growth Results Expanded

Manufacturing		Computer Manufacturing		High Services		FIRE		Retail	
Total Employ-ment	Real Income per Worker	Total Employ-ment	Real Income per Worker	Total Employ-ment	Real Income per Worker	Total Employ-ment	Real Income per Worker	Total Employ-ment	Real Income per Worker
64782	$25,762	64782	$25,791	64782	$25,584	64782	$25,542	64782	$25,469
61215	$26,224	61216	$26,254	61204	$26,034	61215	$25,991	61212	$25,912
58021	$26,612	58026	$26,643	57999	$26,408	58026	$26,362	58027	$26,274
55509	$26,847	55523	$26,878	55481	$26,628	55527	$26,577	55538	$26,477
53611	$26,920	53635	$26,950	53753	$26,688	53817	$26,630	54114	$26,518
52391	$26,878	52424	$26,907	52237	$26,622	52322	$26,557	52360	$26,427

Table 5.9: TFP Growth Results Expanded

Manufacturing		Computer Manufacturing		High Services		FIRE		Retail	
Total Employ-ment	Real Income per Worker	Total Employ-ment	Real Income per Worker	Total Employ-ment	Real Income per Worker	Total Employ-ment	Real Income per Worker	Total Employ-ment	Real Income per Worker
64782	$25,651	64782	$25,700	64782	$25,623	64782	$25,591	64782	$25,624
61202	$26,102	61194	$26,150	61214	$26,065	61182	$26,035	61199	$26,068
57995	$26,478	57975	$26,526	58023	$26,431	57951	$26,406	57984	$26,440
55470	$26,701	55440	$26,751	55518	$26,642	55398	$26,627	55443	$26,665
53684	$26,764	53644	$26,814	53880	$26,695	53570	$26,689	53521	$26,734
52212	$26,702	52281	$26,765	52286	$26,624	52084	$26,629	52136	$26,681

Table 5.10: Capital Growth Results Expanded

Manufacturing		Computer Manufacturing		High Services		FIRE		Retail	
Total Employ-ment	Real Income per Worker	Total Employ-ment	Real Income per Worker	Total Employ-ment	Real Income per Worker	Total Employ-ment	Real Income per Worker	Total Employ-ment	Real Income per Worker
64782	$25,664	64782	$25,712	-	-	64782	$25,593	64782	$25,626
61202	$26,116	61017	$26,184	-	-	61191	$26,038	61206	$26,071
57994	$26,493	57830	$26,555	-	-	57969	$26,408	57998	$26,444
55470	$26,718	56007	$26,724	-	-	55427	$26,628	55465	$26,668
53676	$26,782	53625	$26,829	-	-	53615	$26,690	53552	$26,737
52209	$26,721	52854	$26,814	-	-	52249	$26,638	52170	$26,684

6. CONCLUSIONS

6.1 CONCLUSIONS

The industrial mix is a relevant issue facing urban economies as the modern economy transitions from an industrial to a post-industrial service-based. Given the changing industrial mix at both the national and urban levels and its effects on regional characteristics, this dissertation has extended the research and understanding of the impacts of the industrial mix on the urban environment and has begun to analyze its optimization for use in local policy and by urban and regional planners. This objective was accomplished through three essays that implement the use of a computable general equilibrium (CGE) model.

The first essay demonstrated that identical increases in aggregate metropolitan employment originating from growth in individual productive sectors result in different average urban density measures and that sector growth under optimality has the ability to spatially expand the city and reduce population density. The results suggested that certain urban characteristics are important in determining density's relationship to productivity and that city finances are strained as cities lose manufacturing and gain service sectors.

The second essay estimated the impact of the industrial mix on the local environment from a land use perspective and evaluated the optimal combination of sectors for a proposed development project using a range of efficiency variables. The results provided a number of insights for policy makers. First, high-wage services yield the largest increases of population and household income whereas retail's modest indirect effects make it attractive to areas with limited available land. Second, individual sectors have unique land requirements (or land multipliers) that can be parsed into commercial and residential land to derive optimal zoning policies. Third, the results reveal *sector growth complements*: sectors that interact with each other to increase efficiency measures. Finally, the results demonstrated the importance of traditional manufacturing to medium and small cities; however, if manufacturing is unavailable, export growth in retail or tourism can substitute and increase most efficiency or objective measures.

The third essay analyzed the industrial mix in the context of optimal city size. This essay estimated optimal city size with pecuniary externalities given the inefficiency provided by the unequal distribution of land and capital rent inside the city. The essay was able to determine the degree of overpopulation within a city and estimated the shifts due to changes in the industrial mix. The results showed that a relative increase in export growth for services led to a larger city size compared to export growth in manufacturing, whereas total factor productivity growth in manufacturing sector led to a larger optimal city size than productivity growth in services.