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Office market adjustment to alternative workplace strategies

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Abstract

Regional CGE models have been a valuable tool for regional development and regional policy analysis and can have valuable applications in real estate analysis as well. This paper describes the Colorado Real Estate (CO-RE) Computable General Equilibrium (CGE) model and its application to the analysis of the impacts of alternative workplace strategies (AWS) such as office hoteling on regional property markets and the regional economy. AWS, modeled as a productivity-enhancing "technological" improvement that reduces firms' office space requirements, is shown to spur investment in non-office sectors through a positive impact on local economic growth. The impact on local government finances may be negative due to falling office property values. The impact of a sudden, permanent drop in underlying demand for office space by office-using sectors includes dramatic if sluggish decreases in rents and increases in office vacancy.

Keywords: office market, real estate, computable general equilibrium, remote work, alternative workplace strategies

1. Introduction

Data suggests that office square footage used per worker declined significantly during the great recession and recovery from it (Miller, 2012). Surveys conducted by CoreNet Global, the Building Owners and Managers Association International (BOMA, 2011) and others indicate a trend toward increased efficiency of office space usage. This trend can be attributed to a variety of changes the way businesses operate referred to as alternative workplace strategies or AWS (CoreNet Global, 2009), including telework, office hoteling, open floor plans and more, a transition to which has been ongoing for decades. CoreNet Global (2012) forecasted a decline in actual office space usage per worker in the neighborhood of 1/3 from 2010 to 2017 and gave a "best practice" target of only around ½ of the nationwide average in office space per worker as of 2010. Managers may not follow through with stated plans (Miller, 2012) and prior to the COVID-19 pandemic the transition was slow. However, the forced experience of office closures and remote workplaces led to an immediate spike in remote work and a renewed emphasis on AWS and a rationalization of the usage of office space (Dessalines, 2023) including resizing their office footprint, with Boland et al. (2020) projecting that firms could reduce their real-estate costs by 30 percent or more.

An accurate forecast of office demand - as well as how a long-run trend toward more efficient utilization of office space will affect rents, prices and construction - will be of paramount importance to owners, managers and investors in office property. However, the broader impacts of such a transition on a regional economy may also be significant. Improved efficiency would lower costs and increase profits for firms in office-using sectors, but decreased office rents and property values could mean lower tax revenues and income from property investments for local households. If efficiency gains lead office-using sectors to expand, this might increase demand for other property types but low rents might lead some firms to substitute or repurpose office space instead.

The concepts of alternative workplace strategies and telecommuting are intertwined in practice, in the literature and in public perception. Though this study focuses on the impacts of alternative workplace strategies, some explanation of the two concepts and most importantly how they differ may be required. In principle the terms telework or telecommuting refer to replacing a physical commute to the office with telecommunications technology, which eliminates the need to be

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physically present at a given location in order to perform critical job responsibilities. The result can be that a home office replaces a work office, with less commercial office space utilized by that particular worker at least at certain points during a workweek. According to Safirova (2002) the concept of telework or telecommuting was first researched by Nilles with case studies on productivity and social implications. As Safirova (2002) and Nilles (1988) have described, chief among the promoted benefits of telecommuting were assumed to be a reduction in traffic and time spent behind the wheel and flexible working hours which would improve the standard of living and productivity for telecommuters by improving their ability to balance the demands of work and family.

It should be noted that where there is a connection between telecommuting and adoption of AWS, the connection could be lagged or contemporaneous. This study will analyze the impacts of a transition to AWS and it is therefore a relevant question whether there should be any strong expectation that recent trends toward AWS occur contemporaneously with trends toward increased telecommuting. Studies such as Noonan and Glass (2012) have shown that the prevalence of telecommuting had not risen greatly since the 1990s after reaching approximately 20% of the urban workforce (including those who work from home occasionally), and perhaps not in such a way as to truly transform the nature of work. According to Boland et al. (2020) this figure rose to 25% by 2019 before spiking to 62% at the peak of the COVID-19 pandemic. Though the dataset used by Noonan and Glass was discontinued after 2004, other sources (Walls et al., 2007) corroborated the finding. There is no doubt, however, that remote work and telecommuting increased dramatically during and following the COVID-19 pandemic, with a tripling or quintupling of job listings explicitly offering remote work (Hansen et al., 2023). According to Boland et al. (2020) this figure rose gradually to 25% by 2019 before spiking to 62% at the peak of the COVID-19 pandemic. By early 2023 this had fallen to 13% of full-time workers that were fully remote and 28% that worked hybrid models (Dessalines, 2023). In spite of return-to-work strategies by many firms, the share of workers that telecommute at least part of the time remain elevated. The forced experience of the remote workplace during the pandemic likely broke down reluctance from some managers that feared low productivity or a disruption to firm culture (Ozimek, 2020).

Recent research may suggest some reasons why this might be the case, though arguments for and against remote work or telecommuting are varied and contradictory. According to a survey based study by Neufeld and Fang (2005) 47% of telecommuters reported higher self-assessed productivity than when they were working from the office, but the remaining 53% reported lower self-assessed productivity. Among those who reported lower productivity, key reasons given were the lack of face-time with managers and co-workers and distractions involved in mixing work and family. Noonan and Glass (2012) found no evidence that those who would theoretically benefit from flexible work schedules, namely those with children, were more likely to telecommute. Singles were found to be more likely to telecommute than married people as well, perhaps because while the benefits of flexible hours for work/family balance do improve well-being such situations are not inherently conducive to productivity. This result is confirmed by Safirova and Walls (2004) who find that telecommuters are more likely to be male and from smaller households.

According to an experiment by Dutcher (2012) productivity for telecommuters is higher than for those in the office only for creative tasks, while for mundane tasks productivity in the office is higher. These findings are supportive of the idea that, in terms of productivity, telecommuting is appropriate only for certain workers in certain work situations and is not without drawbacks. Emanuel & Harrington (2024) found evidence that less productive workers self-select into remote jobs and that potential savings for the firm in other areas are not sufficient to offset this productivity loss. Faruque et al. (2024), on the other hand, in an analysis of remote work for small businesses found increases in productivity due to reduced interruptions and flexible schedules. Ozimek (2020) found that a greater share of managers surveyed considered that remote workers were more productive than less productive.

In terms of improvement in quality of life for the telecommuter, it is clear that many workers do prefer remote work with analysis by Boland et al. (2020) finding satisfaction with the arrangement at 80%. However, Noonan and Glass (2012) found that the only variable that strongly varied between telecommuters and non-telecommuters was increased work hours for telecommuters, as they may be "always on call". In addition, Peters et al., (2004) found that a majority of those who had been offered the opportunity to telecommute had declined. In explanation Safirova and Walls (2004) find that those workers most enthusiastic about telecommuting are those with less education who are less likely to be allowed or encouraged to telecommute by managers perhaps because the tasks involved in their work would be more "mundane" and their productivity would be negatively affected. There are also common complaints about the nature of remote work, particularly the experience of online meetings rather than those held face to face. If this is the case, we may not expect a strong push for telecommuting from workers themselves or any kind of a hedonic wage effect.

It has also been proposed that an important benefit for telecommuters would be reduced time spent in traffic. According to a survey of the literature by Walls and Safirova (2004) most studies indicated reduced vehicle miles by telecommuters, however many studies looked only at travel to the workplace. Sridhar and Sridhar (2003) found empirical evidence for a complementary relationship between telecommuting and face-time, either with clients or managers. This need by those who telecommute to commute in order to meet face to face with others may explain why many telecommute only part of the time as Zhu's (2012, 2013) findings using a larger sample and more recent data than those included in the survey by Walls and Safirova that telecommuters make longer trips to work (though less frequently) and engage in more non-commute work travel. Zhu's findings cast some doubt on the oft-assumed negative relationship between telecommuting and vehicle miles traveled or congestion. The mechanism suggested is that remote workers may choose to live farther from their offices, in larger homes in more pleasant neighborhoods. Balemi et al. (2021) found some apparent evidence of an increase in housing demand resulting from remote work during the pandemic while Ahrend et al. (2023) also found an increase in relative housing demand for homes in rural areas just outside of metropolitan boundaries, indicating longer but less frequent commutes by hybrid workers.

As detailed by Becker and Steele (1990, 1995) Alternative Workplace Strategies or AWS is a concept from the discipline of facilities management and like the concepts of remote work and telecommuting, not new. Fundamentally, AWS refers to the elimination of assigned workspace and movement towards shared workspace through what is often referred to as "office hoteling" or "hot desking"[1]. As Haynes and Price (2004) note: "offices or workstations are notoriously underutilized" (p. 9) and this tendency is exacerbated by increases in the prevalence of telecommuting. As such, a transition to AWS involves a rationalization (Duffy, 2000) of the office in response to current usage patterns rather than a drive to change usage patterns. As Duffy (2000) laments, the pace of change in office organization has been slow and has not kept up with predictions made decades earlier with blame laid upon conservatism by suppliers and organizational hierarchies. However, the process was greatly accelerated by the COVID-19 pandemic and we are now in a phase of office footprint rationalization, both in form and quantity, in response to changes in the labor market and workplace that have already largely occurred (Boland et al., 2020).

The reduction in costs (Duffy 2000; Sridhar & Sridhar 2003; Young 1995; Kaczmarczyk 2005) has been the predominant concern for individual firms transitioning to AWS with potential impacts on workplace productivity either ignored or simply less touted. To the extent that telecommuting increases office underutilization a transition to AWS could be due to a concurrent increase in telecommuting, but as such office rationalizations may occur with significant lags it may be more likely a reaction to past increases in telecommuting. If related to concurrent increases in telecommuting, the empirical impacts of telecommuting on worker productivity, worker quality of life and vehicle miles traveled remain ambiguous. Where office workers are frequently away from their assigned space for reasons other than telecommuting; business travel, meetings, etc… AWS

[1]The two concepts differ only in whether shared office space is available on a first-come first-serve basis (hot desking) or is reserved for some period in advance (office hoteling) (Gibson, 2003)

may produce the same benefits. For these reasons, this study will model a transition to AWS, whether occurring contemporaneously to a transition to remote work or at a lag, exclusively as a reduction in operating expenses for affected firms due to decreased office space requirements. The impact of AWS on space requirements is unambiguous and, according to Duffy (2000) has always been the chief driver of the trend, while the impact of AWS or remote work on productivity, job satisfaction, traffic congestion and consumption patterns remain ambiguous or context specific.

This paper describes a regional computable general equilibrium (CGE) model, the Colorado Real Estate (CO-RE) model, designed for analysis of impacts originating in or of particular relevance to local property markets and its application to the issue of reduced office space per worker requirements. The model represents the Colorado economy in a baseline year, built upon a series of key assumptions: perfect competition, market clearance, utility maximization by households and profit maximization/cost minimization by firms. The model features, in addition to 24 industry sectors and 7 household groups defined by household income, 5 labor groups and 7 tax categories, 20 capital categories corresponding to important classes of real and personal property. The model can estimate the impact of exogenous shocks and changes in production technology (as in the case of office sharing) on regional real estate markets as well as the impact of shocks to regional real estate markets on the broader economy, regional employment and tax revenues.

2. Model Description

A Computable General Equilibrium (CGE) model is a whole-economy simulation incorporating profit-maximizing firms, utility-maximizing firms, government entities, interregional migration and trade and endogenous supply of factors of production. As illustrated in Figure 1, the structure of the economy follows a circular flow: households are endowed with factors of production (labor, land, and capital) as well as streams of income from outside the region (such as social security income) and demand goods and services and housing. Firms rent factors of production from households and demand intermediate goods from other firms, using these to produce an output that can be sold to local households, local government entities and exported outside the region. Local governments levy taxes, revenues from which are spent on goods and services as well as factors of production. Production and consumption decisions depend upon relative prices; endogenous supply of factors of production depends upon returns.

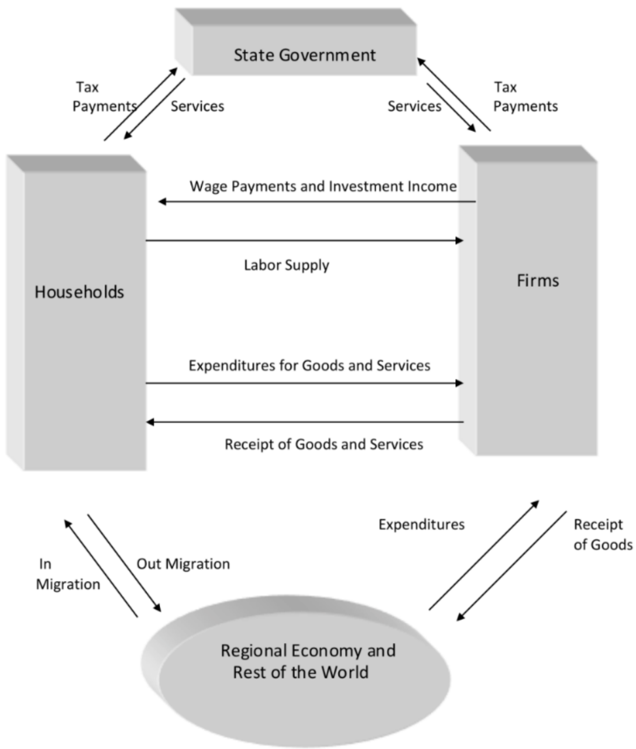

Figure 1 The structure of the economy

The CO-RE model incorporates seven representative local household groups defined by income level ranging from RAH(1) with incomes under $10,000 to RAH(7) with household incomes greater than $100,000 as well as a non-local household group representing owners of Colorado capital and land outside the region. Each representative household is endowed with a certain initial allocation of land, each of five types of labor and each of twenty types of capital. In addition local household groups receive exogenously determined streams of non-Colorado sourced income such as pensions, social security payments and returns to prior investments. Average income levels for each Colorado household group are shown in Table 1 below, note that incomes include implicit rents for owner-occupied housing.

Table 1 Household Groups

Household Group	Average Income
HH1	$21,898
HH2	$26,019
HH3	$44,172
HH4	$58,329
HH5	$73,156
HH6	$118,757
HH7	$185,384

The representative non-local household group (RAF) is endowed with land and each type of capital, but not with labor. The majority of local household capital endowments are composed of single-family residential capital with proportions derived from 5-year American Community Survey (ACS) public use microdata (PUMS). The majority of the non-local household endowment is composed of multi-family and non-residential capital. Local households demand only welfare produced using a consumption bundle of Demand for Colorado exports is represented by a separate household group endowed with a steam of "foreign exchange", non-Colorado sourced and monetary income.

The CO-RE model includes, in addition to a single homogeneous land type, five labor groups defined by relative wage level as a proxy for skill level. Average annual wages for each labor/leisure group are given in Table 2 below, note that no distinction is made between full-time and part-time work. Wage and employment data is derived from the Quarterly Census of Employment and Wages for the state of Colorado.

Table 2 Labor Groups

Labor Group	Average Wage
L1	$7,870
L2	$41,789
L3	$68,699
L4	$95,317
L5	$197,176

One novel innovation of the Colorado Real Estate model is the inclusion of 20 types of capital based upon asset definitions used by the US Bureau of Economic Analysis in their National Income and Product Account (NIPA) tables. Estimates for the total residential and non-residential capital stock for the state of Colorado are obtained from the Colorado Department of Local Affairs (DOLA) Property Tax Division, estimates for the breakdown of non-residential capital into real and personal property categories are obtained using asset proportions from the NIPA tables adjusted to reflect the structure of the Colorado economy. A list of property types used and the corresponding NIPA definitions can be found in the appendix.

The Federal government collects income tax and payroll tax revenues, all of which flow out of the region. State and local governments are funded by retail sales taxes, levied on sales of goods and services in proportions derived from Colorado Department of Revenue data, personal income taxes, business income taxes, property taxes and fees for permits or services. State and local tax revenues are used to fund five government service sectors: education, administration, justice/law enforcement, transportation and health.

Production sectors are largely organized along the lines of 2-digit National Industry Classification System (NAICS) definition with the Mining and Utilities sectors split into subsectors. In addition, production of housing services is organized into six sectors for multifamily housing, attached housing and four detached single family housing sectors grouped by price range. Government services are organized into production sectors as mentioned above but are demanded solely by state and local governments and funded solely by tax revenues. Figure 2 gives a complete list of production sectors.

Mathematically, production of goods and services is assumed to take place using a nested constant elasticity of substitution (CES) functional form. Reference input and output quantities for production functions are obtained by scaling IMPLAN input-output proportions to fit BEA regional output quantities for the reference year. To reflect complementarity between labor and capital (and between different capital types) an elasticity of substitution between labor and different capital types (and therefore for substitution between capital types as well) is set at 0.4 for all production functions following Kemfort (1998) and Young (2012). Intermediate goods used in production are included in a Leontief nest with elasticity of substitution of zero. Substitution elasticities between these two nests and land are set to one as has been empirically estimated (Thorsnes, 1997 ; Clapp, 1979). The resulting two-level nested CES production function, as illustrated in Sato (1967), has the basic CES form but will lack the constant elasticity of substitution property (Uzawa, 1962). For each industry "I", within the capital/labor (kl) nest, within the land nest and within the intermediate (j) nest substitution elastiticities in producing the input aggregates $Z_{i,kl}$, $Z_{i,land}$ and $Z_{i,j}$.

equation 1.1.) $$Z_{i,(kl)} = \left[\sum_{kl=1}^{KL} \beta_{i,kl} Q_{i,kl}{}^{(0.4)-1/0.4}\right]^{-\sigma(kl)/1-\sigma(kl)} where\ \sigma_{(kl)} = 0.4$$

equation 1.2) $$Z_{i,(land)} = \left[\beta_{i,land} Q_{i,land}{}^{\sigma_{land}-1/\sigma_{land}}\right]^{-\sigma_{land}/1-\sigma_{land}} where\ \sigma_{land} = 1$$

equation 1.3) $$Z_{i,(j)} = min\left(\beta_{i,j} Q_{i,j}\right)$$

equation 1.4) $$Y_i = \left[\alpha_{i,(kl)} Z_{i,(kl)}{}^{\sigma/1-\sigma} + Z_{i,land}\alpha_{i,land}{}^{\sigma/1-\sigma} + \alpha_{i,(j)} Z_{i,(j)}{}^{\sigma/1-\sigma}\right]^{-\sigma/1-\sigma} where\ \sigma = 1$$

Goods and services consumed as intermediate inputs or in the generation of welfare/utility for household consumption are first aggregated with their non-local equivalents following an Armington (1969) formulation. Domestic households consume only welfare/utility, produced using goods and services and housing with a CES specification much like that for goods and services. Elasticities of substitution in production of utility/welfare are set to 1, a Cobb-Douglas functional form. Each representative households consumption bundle "d" includes 24 goods or services and 6 housing categories.

equation 1.5) $W_h = \prod_{d=1}^{D} Q_{h,d}{}^{\gamma_{h,d}}$ *where* $\gamma_{h,d}$ *represents the proportion of spending on* $Q_{h,d}$ *in household*

h's budget

The endogenous supply of land as existing land is zoned, platted and prepared for development is represented through a side constraint equation which sets households' endowment of land relative to the current price of land with an elasticity of 2.5. Empirical estimates for the price elasticity of the supply of developable land vary dramatically with local geography, economic conditions and policies. However, even empirical estimates of a single nationwide elasticity, which might be more broadly applicable to large regions such as US states, range from near-zero to near-infinite. Capital supply is treated as a positive endowment to local and non-local households; capital investment expenditures to build new capital or offset depreciation of existing capital are treated as negative endowments. Capital supply and capital investment expenditures for each capital type are subject to a similar constraint with a single-period elasticity of supply of unity (Goolsbee, 1998). Lower estimates of the elasticity of capital supply (Zheng et al., 2012) based on data from urban areas may not be applicable to larger aggregated regions such as US states, in which much development is suburban or exurban and less constrained by policy and land availability. In the dynamic model, capital and land supply constraints follow a "moving average" process, which will cause short-run deviations in prices to die out over time.

The representative local household's endowment of labor is also set subject to two side constraints to first represent migration into or out of the state (MIG(h)) and second flexible labor supply decisions by existing households (LSUP(h)) as a result of changes in wages, employment opportunities and the cost of living. As studies have shown very limited migration responses to tax and wage differentials (Day & Winer, 2006; Coomes & Hoyt, 2008; Young & Varner, 2011) the single-period elasticity of migration with respect to changes in the real wage is set to 0.1, the elasticity of labor supply by existing households with respect to changes in the real wage is set to 0.3 (Eviers et al., 2008). In the dynamic model, migration responses follow a "moving average" specification, with continuing in-migration so long as the real wage remains above the baseline. Labor supply responses by existing households are one-off, so over a long time period the labor supply response by non-residents will dominate (Bartik, 1993).

3. Real Property Markets

Commercial property markets have been understood to be characterized by certain specific features and phenomena (Pyhrr et al., 1999; McDonald 2002) including slow adjustment of stocks and price, disequilibrium and cyclicality without attention to which economic impacts of or on commercial property markets cannot be accurately understood or explained. Through side equations the CGE model is adapted to fit the general Torto-Wheaton stock adjustment model (Wheaton 1987; Wheaton et al., 1997) with some adaptations to fit the idea of a balanced-growth path and some limitations of the Arrow-Debreu general equilibrium framework. Torto and Wheaton model absorption, period-to-period changes in occupied stock of a given real property type, as the product of the slow adjustment process from desired occupied space ($OCCSF^*_t$) from the previous periods occupied space ($OCCSF_{t-1}$) where desired occupied space is a function of the number of office workers (EMP_t) and an interaction term between the number of office workers and lagged office rents (EMP_tR_{t-1}).

The occupied stock adjustment equation $OCCSF_t - OCCSF_{t-1} = \tau(OCCSF_t^* - OCCSF_{t-1})$ (1)

Becomes $ABSORPTION_t = \tau(\beta_0 + \beta_1 EMP_t - \beta_2 EMP_t R_{t-1}) - \tau OCCSF_{t-1}$ (2)

New construction starts in the Torto-Wheaton model are a function of current rents (R_t), current vacancy rates ($vacper_t$), current interest rates (I_t) and a current construction cost index (CCI_t). In the absence of data for construction starts, net changes in stocks (S_t) can be modeled as a function of lags of these independent variables.

$$S_t - S_{t-1} = \gamma_0 + \gamma_1 R_{t-1} - \gamma_2 vacper_{t-1} - \gamma_3 I_{t-1} - \gamma_4 CCI_{t-1} \quad (3)$$

The absorption and construction equations combined with the identity

$$VACANCY_t = S_t - OCCSF_t \quad (4)$$

determine vacant stock ($VACANCY_t$) and the vacancy rate ($vacper_t$) relative to total occupied stock. The addition of a price adjustment equation incorporating the observed negative relationship between rents and vacancy rates completes the system of equations, in which each variable of interest can be explained by lagged values and exogenous shocks to employment, interest rates and construction costs.

$$R_t - R_{t-1} = \sigma(R_t^* - R_{t-1}) \ (5)$$

$$P_t = \sigma\left(\alpha_0 - \alpha_1 vacper_{t-1} + \alpha_2 \frac{ABSORPTION_{t-1}}{OCCSF_{t-1}}\right) + (1-\sigma)P_{t-1} \ (6)$$

It has been observed by Wheaton and Torto (1988), Grenadier (1995) and others that regional property markets do not adjust to shocks at the same speed nor do they exhibit identical characteristics such as natural or baseline vacancy rates. As such we have estimated values in three-stage least square for the parameters in equations (1) through (6) using CBRE data on the office market in the Denver metropolitan area to represent the State of Colorado rather than applying and scaling earlier published estimates for the United States as a whole. Variable values are scaled such that the 2010 values in the CBRE dataset are equal to the starting values in the Social Accounting Matrix; rents are normalized to unity and values for stocks and employment converted to abstract "units of capital" and "units of labor" as in the SAM. Parameter estimates for the absorption, construction (Ct) and rent equations are shown below with T-statistics in parenthesis. Estimates show a negative but insignificant relationship between lagged absorption rates and current rents, but a strong positive contemporaneous relationship between the two so lagged absorption rates have been replaced with contemporaneous absorption rates in equation (9).

$$ABSORPTION_t = 0.31\left(\frac{303.981}{(33.087)} + \frac{0.081}{(0.016)}EMP_t - \frac{0.009}{(0.005)}EMP_t R_{t-1}\right) - \frac{0.31}{(0.144)}OCCSF_{t-1} \ (7)$$

$$C_t = \frac{-45.693}{(28.474} + \frac{76.826}{(10.476)}R_{t-1} - \frac{67.665}{(29.331)}vacper_{t-1} - \frac{15.664}{(24.457)}CCI_{t-1} - \frac{0.252}{(2.157)}I_{t-1} \ (8)$$

$$R_t = \frac{0.608}{(0.13)} - \frac{1.27}{(0.248)}vacper_{t-1} + \frac{8.523}{(2.04)}\frac{ABSORPTION_t}{OCCSF_t} + \frac{0.591}{(0.092)}R_{t-1} \ (9)$$

The construction equation (8) is incorporated in the CGE model nearly as-is: converted from net new construction to gross new construction with the addition of (δ)St-1 where δ is the BEA property-type-specific depreciation rate and scaled to fit the BGP with baseline rental rates, vacancy rates, interest rates and construction costs. Rents, vacancy and construction costs are determined endogenously within the CO-RE model, interest rates are an exogenous parameter assumed to be determined outside the region.

Absorption equation (7) shows that slightly under one third of the impact of any change in input demand (using office employment as a proxy) is felt in the first period following the shock and relatively low demand elasticity for real property. Equation (7) likewise requires some transformation to fit the concept of the BGP, eliminating β_0 and scaling up β_1 and β_2 such that at baseline rent levels a 1% increase in EMP_t leads to a 1% increase in the desired level of occupied stock $OCCSF^*_t$. In addition, given a value for τ of 0.31 the economy will not begin on the BGP unless a certain amount of pressure has already built up – a gap between desired and actual occupied stock equal to $(GRO/\tau)OCCSF_{t-1}$ where GRO is the assumed BGP growth rate – so β1 and β2 are scaled up by (GRO/τ) so that the economy begins on and continues on an approximation of the BGP.

Equations (7) and (8) together determine endogenous vacancy, included in the CO-RE model as a "negative endowment" of real property capital types by household groups.

$$VACANCY_t = (1-\delta)VACANCY_{t-1} + C_t - ABSORPTION_t \ (10)$$

An Arrow-Debreu general equilibrium model is not naturally compatible with the idea of sticky prices or exogenous prices or with the concept of disequilibrium – though our vacancy equation avoids this through a modeling technique. As prices are determined endogenously within a CGE model, the positive relationship between absorption and rents occurs naturally. However, it is necessary to parameterize a relationship between rents and vacancy rates through a side constraint setting an endogenous pricing instrument. If such a relationship is not explicitly declared, higher vacancy rates will imply less available stock – all else equal – and put upward pressure on rents rather than downward pressure. This pricing instrument sets SLUGP_K1(t) for each property type equal to the pricing equation (9) above, depending upon SLUGP_K1(t-1) rather than the R(t-1) determined within the model. SLUGP_K1(t) is then used to set an endogenous "tax" or "subsidy" SLUGP_K(t) for each capital type, with owners of capital footing the bill for a "subsidy" or receiving the benefits from a "tax", such that:

$$SLUGP\_K1_t = R_t * (1 + SLUGP\_K_t) \ (10)$$

4. Setting up the Simulations

In a CGE model, the abstract need for or desire to use office space can be separated from the actual demand or utilization. A variety of reasons may exist for a firm's target usage per worker to differ significantly from its actual usage including prices (DiPasquale & Wheaton, 1996) as well as complicating factors such as uncertainty and inflexible contracts (Miller, 2012). Here the change represented by phenomena such as telecommuting and office hoteling is represented in terms of a change in parameterization of the production functions for office-using sectors to reflect a new ability to produce the reference level of output while using 50% less of the "OfficeSF" capital type providing usage of other factor and intermediate inputs remains unchanged. The simulation is further broken down into one in which the change in target office space use is assumed to take place instantaneously, and one in which the change occurs gradually over 7 years.

According to the BEA, all broadly-defined 2-digit NAICS sectors are office-using to some degree. Relative importance ranges from a high of 43.4% of total capital requirements for the Management of Companies and Enterprises sector to a low of 0.94% of total capital requirements for the Accommodation and Food Service sector. Public Administration and government services sectors are assumed to demand none of the capital types utilized by other sectors. While this assumption may seem unrealistic, offices of government entities tend to be government-owned rather than privately owned and as they are not subject to taxation accurate valuation estimates are more difficult to acquire. Since it is unclear, theoretically or empirically, whether a change in business practices (i.e. "technology") leading to more efficient office space utilization should impact only sectors conventionally defined as office-using such as Finance and Insurance or all sectors which demand any amount of the OfficeSF capital type, two pairs of simulations are run. In the first pair, the change in production technology is assumed to impact all sectors equally either immediately (Fast) or over a span of seven years (Slow). In the second pair, the change in production technology is confined to the five sectors with the highest office space requirements, as a percentage of their total capital requirements; Fin, Real, Serv, Manage and Admin[2] either Fast or Slow .

While Miller (2012) proposes that the gap between actual and target office usage can be largely explained by factors such as employee turnover, search costs and delays in hiring and lease length - in a perfectly competitive economy such as that simulated by a CGE model all of that gap can be and must be explained by prices. While there can be a negative capital supply response, by allowing depreciation to occur without capital investment to offset it, this response is neither large nor quick for real property and all properties in existence must be occupied (though this is the functional

[2]Finance and Insurance, Real Estate Rental and Leasing, Professional, Scientific and Technical Services, Management of Companies and Enterprises, Administrative and Support and Waste Management and Remediation Services

equivalent of assuming a constant vacancy rate) by some firm in some sector. Rents will immediately adjust across the board until it becomes worthwhile for some firm to utilize a property for some purpose, perhaps a purpose very different from that for which it was designed. While the model, as presently constructed, does not include the possibility of permanently converting a property from one type to another (due to a lack of data on the costs involved in such a conversion) we can assume that much of the end result of such conversions will show up in added office demand from unconventional sources at low prices.

The impact on office rents is expected to be negative; we should see a decrease in office space demand from office-using sectors, which far outstrip the decrease in supply due to depreciation. The only question is, if we assume instantaneous price adjustment to clear the office market, how large the decline in office rents will be. By assumption, any change in rents will be instantaneously capitalized in assessed property values. As shown in Figure 2 (below) if we assume a sudden shift towards a far lower target level of office space per worker, existing office stock will decrease by a maximum of 2.4% per year (BEA) as existing structures are allowed to depreciate. If allowed to correct immediately and fully, office rents will need to decline by over 80% in the first year in order to clear the market. The market correction will occur only through reductions in stock by depreciation and a slow increase in demand due to economic growth (at an assumed 3% per year). Office rents will recover, though slowly, after the initial plunge but will still be only 1/3 of initial levels after 10 years. It will take over years for rents to recover to 2009 levels at which time office stock growth would resume.

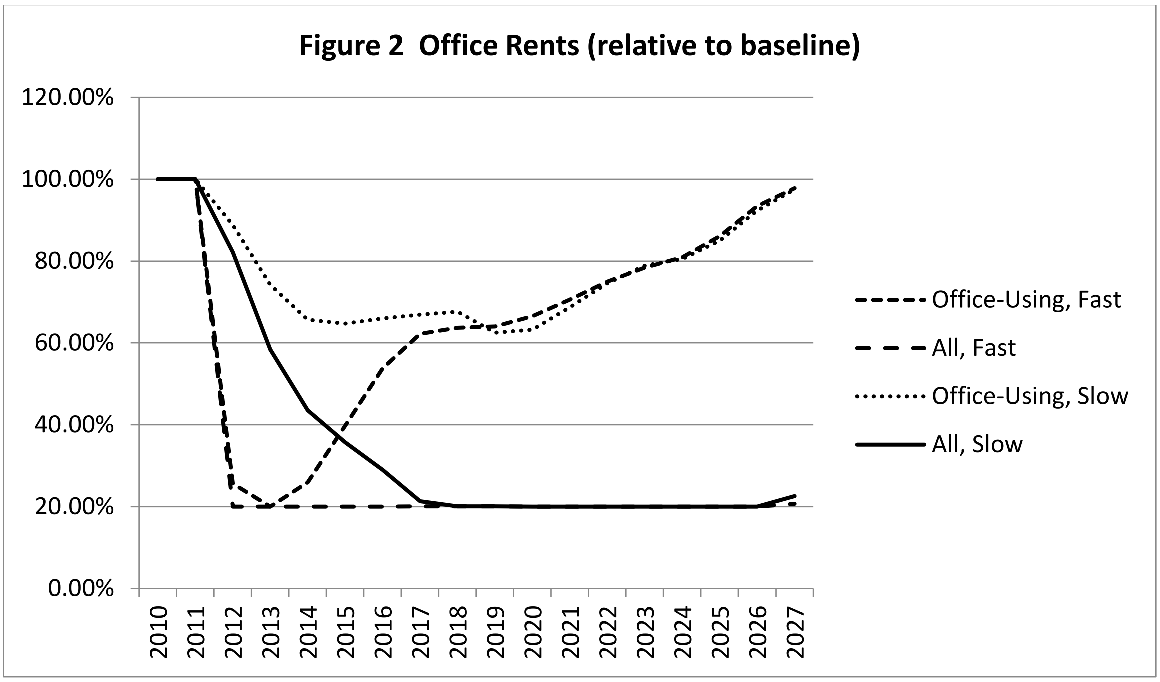

Figure 2 Office rents (Relative to baseline)

Figure 3 (below) shows the effect on vacant office space. In each simulation but the "mildest" (office-using sectors only with a slow transition) we see a dramatic increase in vacancy rates relative to the baseline vacancy rate of approximately 16.5%. However, in no simulation are these high vacancy rates indefinitely maintained. As the regional office market recovers, after a period of low rents and high vacancy rates, those low rents spur additional absorption while the combination of low rent and high vacancy strongly discourages construction. Vacancy rates "overshoot" the baseline 16.5% on the recovery in every simulation as construction is slow to pick up, but return to the baseline given enough time. In the two "office-using" simulations this requires approximately 20 years from the beginning of the initial transition to AWS, for the two "all" simulations even more time is required.

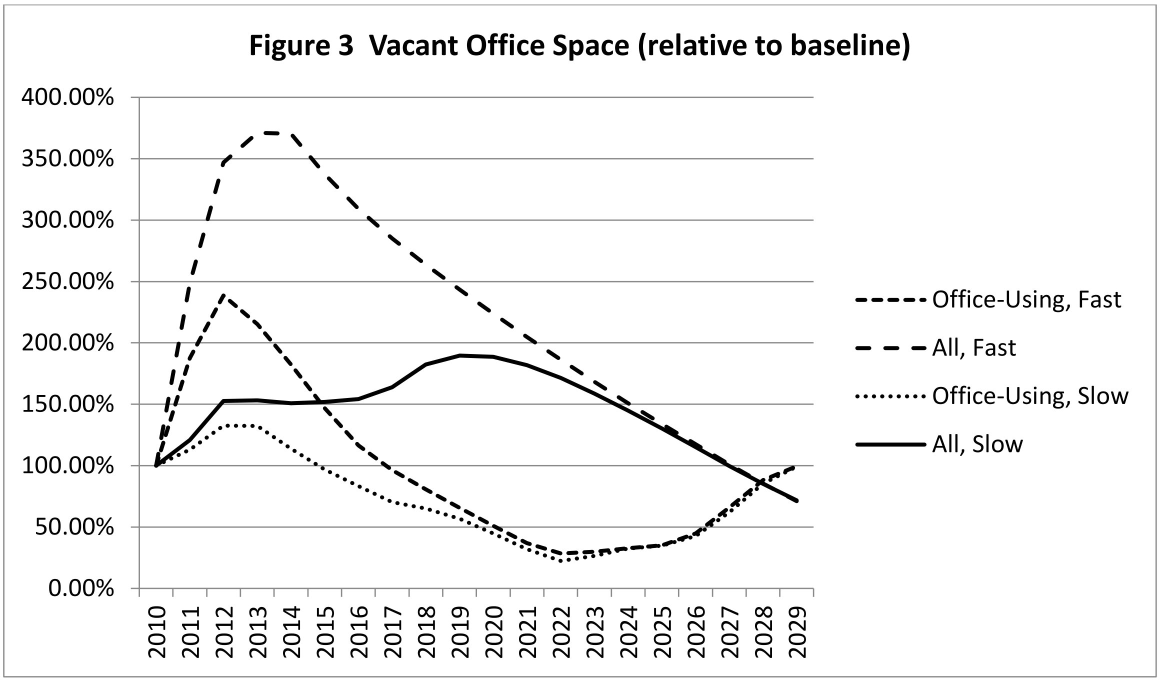

Figure 3 Vacant office space (Relative to baseline)

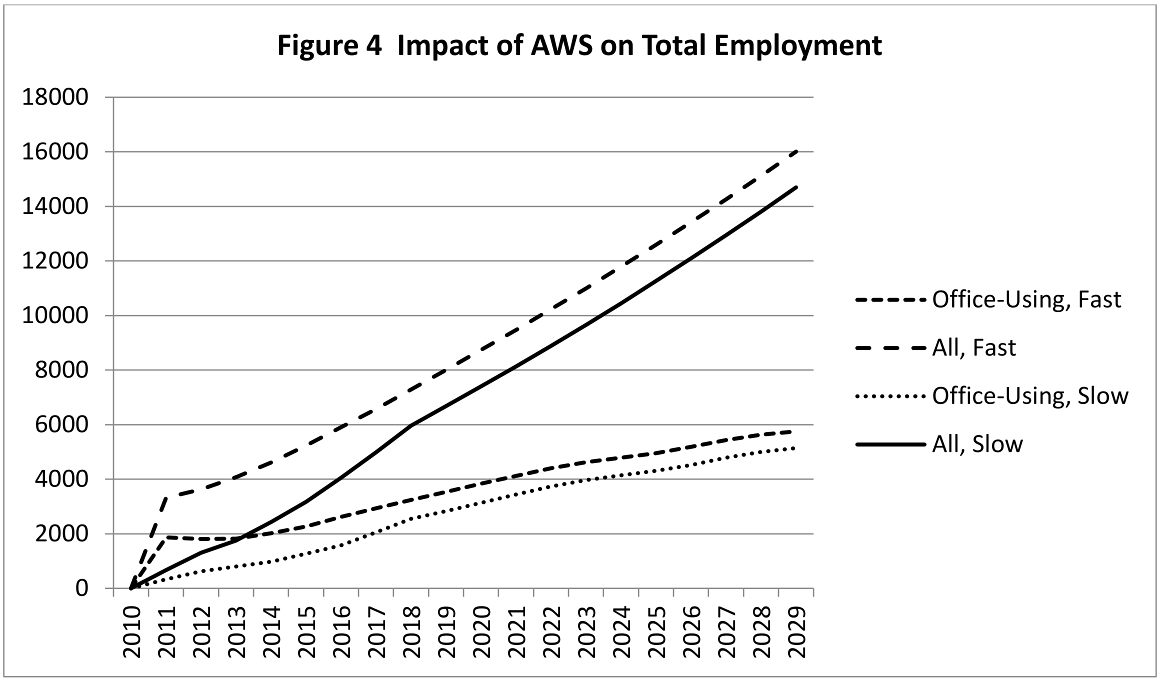

Figure 4 Impact of AWS on total employment

After 10 years, most of the construction boom has run its course and the impact on property values and rents for non-office property types will dissipate. Figure 4 (above) shows the increase in total employment in the state due to the productivity enhancing effects of the transition to AWS. Increases in job creation are significantly more pronounced in the pair of simulations in which all sectors transition to AWS rather than only primary office-using sectors. In part this and the increased impact on total output in Figure 5 (below) can be explained by the dramatic decrease in office rents which further lower the cost of doing business in the state. Once rents have returned to normal levels in the two office-using simulations the impacts on real output begin to slowly diminish.

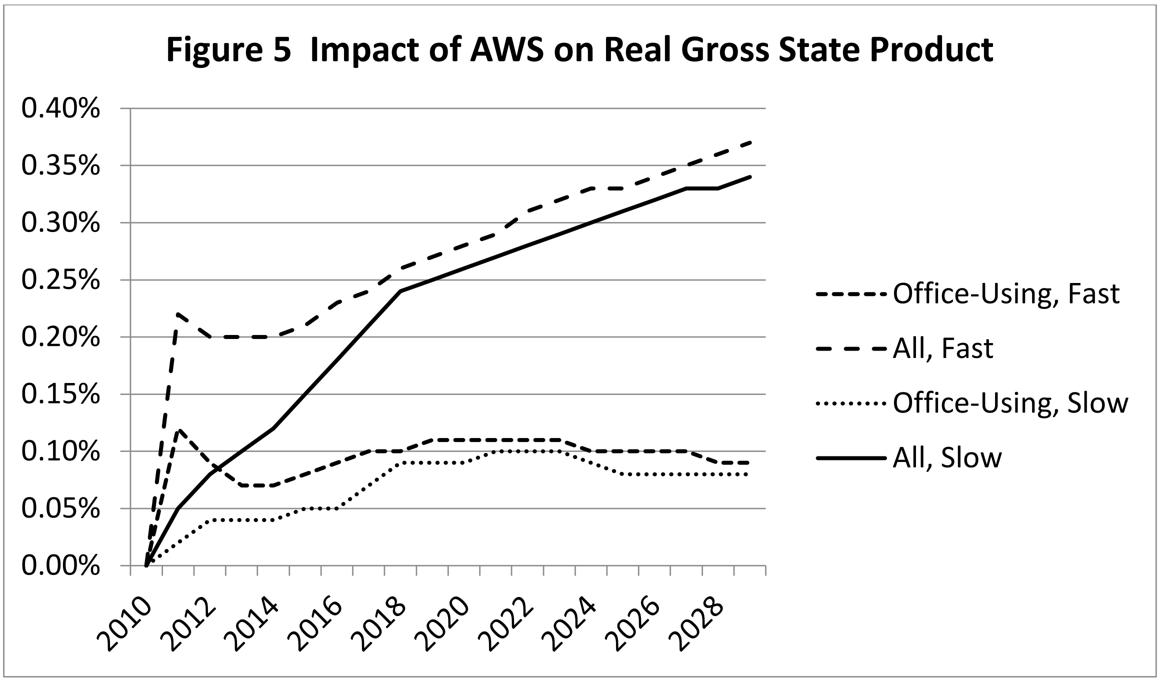

Figure 5 Impact of AWS on real gross state product

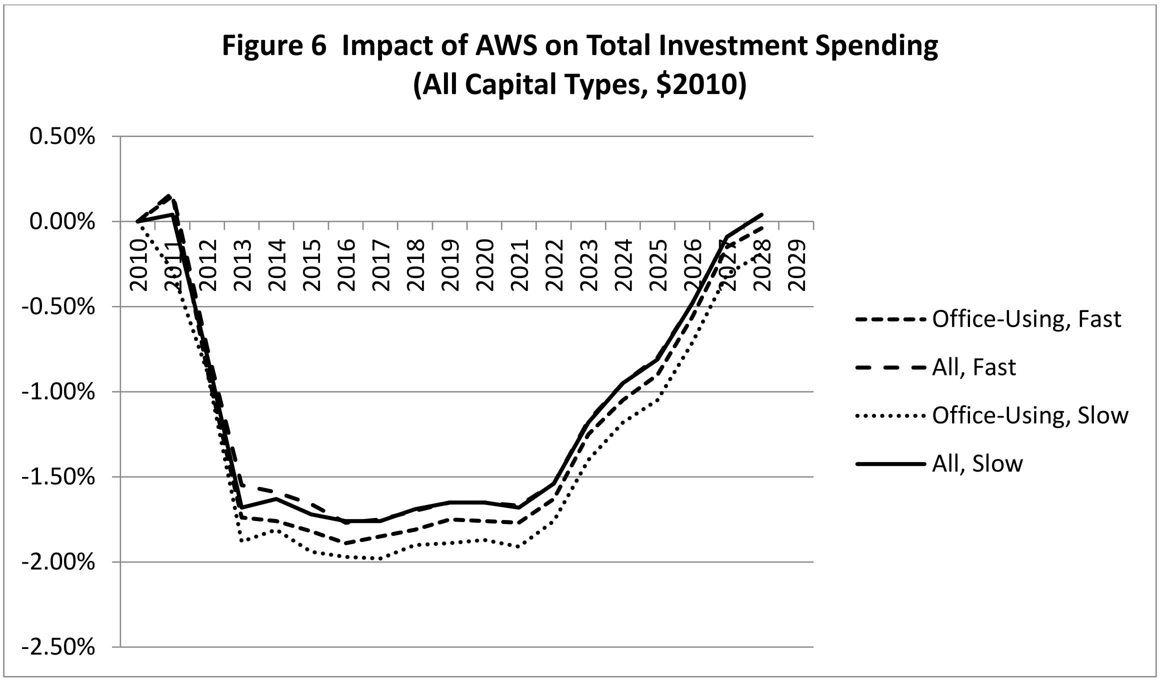

Figure 6 Impact of AWS on total investment spending (All capital types, $2010)

As shown in Figure 7, though the change in business "technology" increases gross state product and leads to the creation of jobs, property tax revenues fall due to the sharp reduction in assessed valuation of office properties. After 20 years, when regional property markets have stabilized, at least in the less extreme "office-using" simulations, the net negative impact on property tax revenues comes to approximately 0.7% or 1.3% of total property tax revenues – relative to 2010 revenues of approximately $5.8 billion. The loss in office property tax revenues on office buildings more than offsets increased revenues from taxes on other property types. This result could be at least partly due to factors unique to the state of Colorado, which depends disproportionately on property taxes levied on commercial property due to the Gallagher Amendment to the state constitution in 1982 limiting property tax increases on residential property. Property tax revenues slowly recover, as office rents/values rise over time and increased investment in other property types increases the tax base but the new steady state which regional property markets approach is one with less real property than would otherwise have existed.

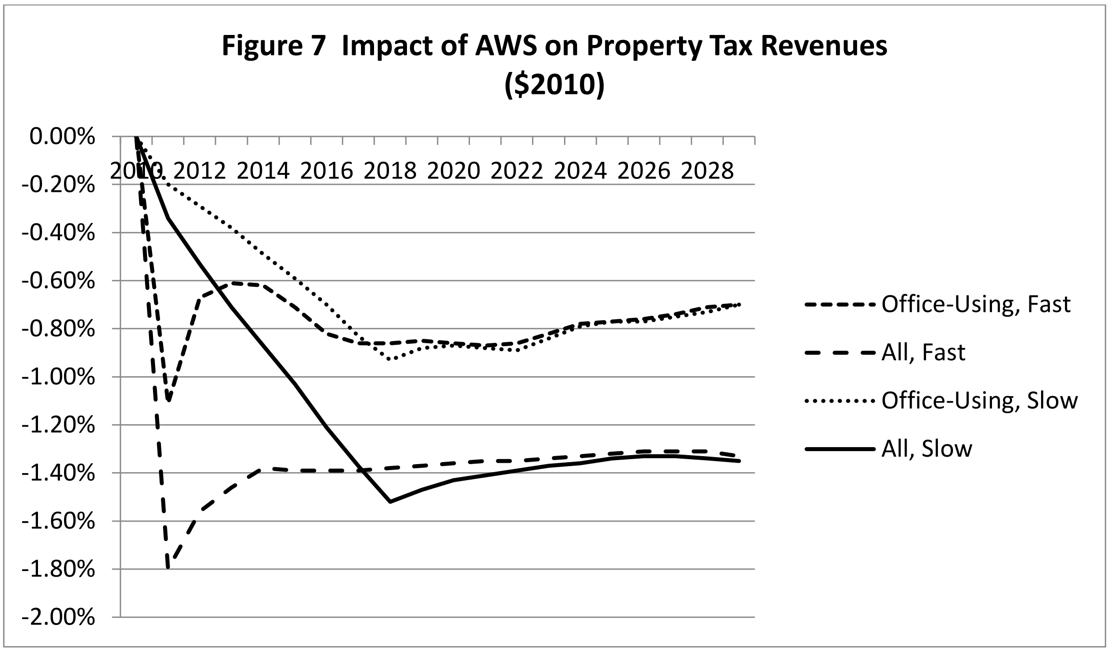

Figure 7 Impact of AWS on property tax revenues ($2010)

As shown in Figure 8 (below), in all simulations the negative impact on local government finances of reduced property tax revenues more than offsets any revenue gains from other taxes and fees. Property tax revenues represent approximately 2/3 of local government revenues in the state of Colorado and approximately ¼ of combined state and local tax revenues. The State government is responsible for covering property tax revenue shortfalls for local school funding in the state of Colorado through the state general fund, so the impact on combined state and local revenues may be a more appropriate benchmark for state policy makers than state revenue alone.

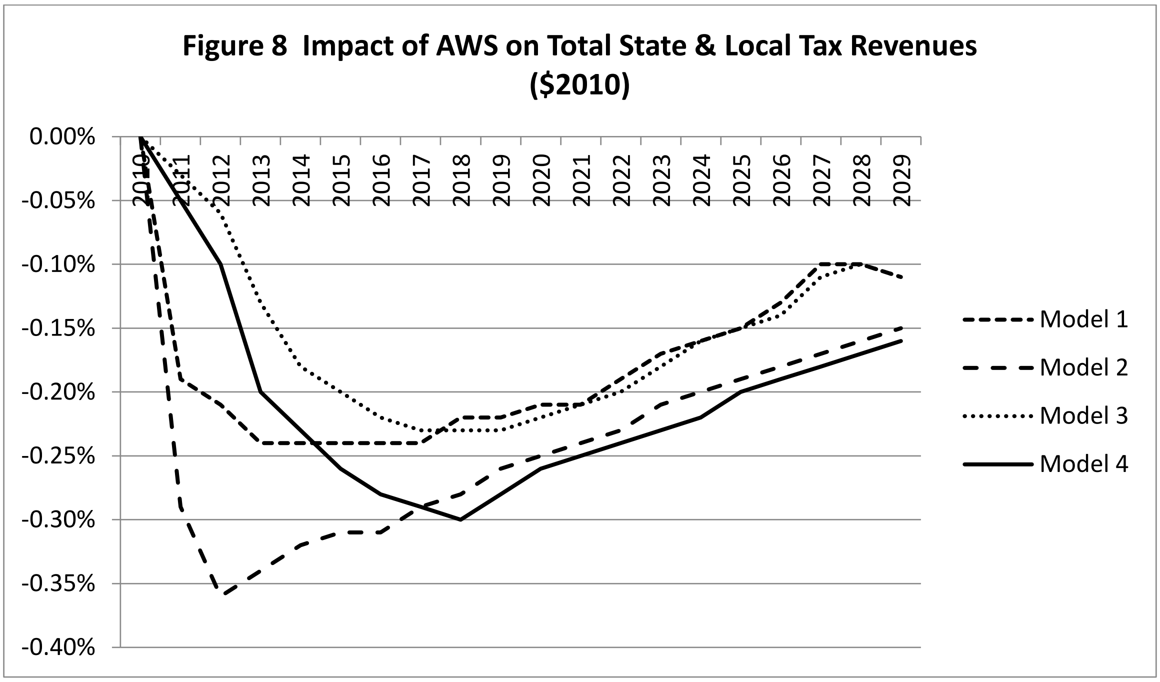

Figure 8 Impact of AWS on total state & local tax revenues ($2010)

5. Conclusion

A regional CGE model such as the Colorado Real Estate model is capable of providing theoretically sound estimates of the impacts of phenomena which input-output and econometric models may be unable to appropriately analyze. When applied to the question of the impacts of alternative workplace strategies such as telecommuting on local property markets and the local economy, estimates provided by the Colorado RE model suggest that the trend will be beneficial for output and employment growth. AWS is expected to spur investment in non-office property types, though increases in non-office commercial rents are expected to be short-lived. Property tax receipts are expected to fall overall due to the greatly diminished valuation of office properties. In the state of Colorado, in which the property tax burden falls disproportionately on the office sector, this fall in property tax revenues more than offsets increases in other tax revenues at all levels of state and local government.

The perfectly competitive market assumptions of most CGE models, including the CO-RE CGE model where real property is not concerned, are usually quite attractive compared to most feasible specifications with market imperfections such as those described in Willenbockel (2004), however the assumption that all markets clear appears untenable when dealing with property markets. The real world office vacancy rate is will display a non-zero average over any significant time horizon and shocks to either office demand or office supply can be expected to influence not only office rents and valuations but also the short-run vacancy rate (De Francesco, 2008). CoreNet Global, for example, suggested that AWS could result in 40% office vacancy rates even after 10 years if all office-using firms followed through on their stated plans to reduce square footage per worker (CoreNet Global, 2012). This is not far from the CO-RE model vacancy estimate for the same scenario, in which all firms in all sectors begin an immediate transition to AWS. In property markets, we should expect significant lags: an immediate shock to demand should result in a lagged impact on vacancies, which will result in a lagged impact on rents and values. This sluggish supply side response built into the Colorado RE CGE model. Although rents are sticky on the downside, the scale of the shock to office demand implied in the CoreNet projection is more than sufficient to cause large and rapid changes in rents.

Central to the results of these simulations is the sluggish adaptation of the office property market to sudden shocks to the demand for space, as we have seen recently. Rents do not adjust quickly, but equally sluggish adjustments to vacancies result in rents which remain depressed for quite some time. Although the overall economic impact of these reductions in the need for office space are positive, they necessitate an approach by managers and policymakers focused on facilitating adaptation in use of space, in more flexible contracts (Pajević, 2021) and in planning and regulation to reduce vacancy.

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Appendix: Model Description

Capital Types (Source: U.S. Bureau of Economic Analysis, 2010)

Model Identifier	NIPA Categories
SingleResSF	
MultiResSF	
TechK	Mainframes, PCs, Printers, Terminals, Storage Devices, System Integrators, Prepackage Software, Custom Software, Own Account Software
OtherK	Communications, Nonelectro Medical Instruments, Electro Medical Instruments, Nonmedical Instruments, Photocopy and Related Equipment, Office and Accounting Equipment, Nuclear Fuel, Other Fabricate Metals, Household Furniture, Other Furniture, Household Appliances, Other Electrical, Other
MachineryK	Steam Engines, Internal Combustion Engines, Metalworking Machinery, Special Industrial Machinery, General Industrial Equipment, Other Agricultural Machinery, Farm Tractors, Other Construction Machinery, Mining and Oilfield Machinery, Service Industry Machinery
GridK	Electric, Transmission and Distribution
AutoK	Light Trucks (including utility vehicles), Other Trucks, Buses and Truck Trailers, Autos
OtherTransK	Aircraft, Ships and Boats, Railroad Equipment

OfficeSF	Office
MedicalSF	Hospitals, Special Care, Medical Buildings
WarehouseSF	Warehouses
MobileSF	Mobile Structures
RetailSF	Multimerchandise Shopping, Food and Beverage Establishments
ManufacturingSF	Manufacturing
InfrastructureSF	Electric, Gas, Petroleum Pipelines, Wind and Solar, Communication, Petroleum and Natural Gas, Mining, Air Transportation, Other Transportation, Other Railroad, Track Replacement, Local Transit Structures, Other Land Transportation, Water Supply, Sewage and Waste Disposal, Public Safety, Highway and Conservation and Development
ChurchSF	Religious
SchoolSF	Educational and Vocational
RecreationSF	Amusement and Recreation
HotelSF	Lodging
FarmSF	Farm

Variable and Parameter Abbreviations and Labels

RAH(1) through RAH(7) – Representative Average Household Income Levels 1 through 7
RAF – Representative Average Non-Local (Foreign) Household
Wh – Welfare level for household group h
Qh,d – Consumption of good d by household h
γh,d – proportion of household h's spending on Qh,d
MIGh – migration of household group h into the region
LSUPh – endogenous labor supply scalar for household group h
EMPt – total employment of office workers at time t
Rt – rent level at time t
R*t – Desired rent level at time t
Rt-1 rent level at time t-1
OCCSFt – Occupied square footage parameter at time t
OCCSF*t – Desired occupied square footage parameter at time t
OCCSFt-1 – Occupied square footage parameter at time t-1
Vacpert – Current vacancy rate
ABSORPTIONt – Absorption at time t, the change in occupied square footage
It – Current interest rate
St – Current stock of real property
CCIt-1 – Construction cost index at time t-1
VACANCYt – Total vacant stock at time t
Ct – Construction at time t
BGP – the Balanced Growth Path, the business-as-usual path in a dynamic simulation
GRO – the assumed growth rate of the economy along the BGP
SLUGP_Kt & SLUGP_K1t – model parameters to force Sluggish Price adjustment for capital at time t

Resume

Christopher Hannum is the Global Economics Programme Director and an Assistant Professor of Economics based at UCA's Khorog Campus. He holds a Ph.D. and MA degrees in Economics from Colorado State University in the United States, as well as a BA in History from Michigan State University. Dr Hannum has more than 10 years of teaching experience in economics. Before joining UCA, he taught at Istanbul Technical University in Turkey for six years as an Assistant Professor of Economics, and at Colorado State University for four years as an Instructor. He has taught a variety of courses, both in-person and online, including Economics, Principles of Microeconomics, Intermediate Microeconomics, International Trade, Environmental Economics, Urban Economics, Managerial Economics, Financial Markets and Institutions, Research Methods I, and Research Methods II at undergraduate and graduate levels. He has academic and research interests in the integration of technology and data science into the economics curriculum, applied policy modelling, and the analysis of property markets.