The Environment and Structural Change

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Abstract

This paper builds and estimates a general equilibrium model with production (pollution) externalities to jointly explain income and price effects for the United States experience of structural change. First, I document the rise of energy-savings technologies and increased tastes for air quality since 1970. Second, I solve a multi-sector model featuring preferences over air quality and estimate it using simulated method of moments. The presence of non-separable preferences between pollution and consumption plays a key role in reconciling joint income and price effects. Since the inclusion of pollution creates non-homothetic preferences, the decline in manufacturing produces a rise in air quality, which occurs at precisely the same time that the price on services is growing. I decompose the contributions of income and price effects by simulating counterfactual models that omit income and price effects separately. Comparing each equilibrium allocation to the benchmark allows me to characterize the relative effects. On average, price effects dominate with the ability to explain 60% of structural transformation, while income effects explain the remainining 40%. Third, I simulate the effects of introducing permanent and temporary pollution taxes. I show that the magnitude of the counterfactual simulations depends crucially on assumptions about income and price effects.

Keywords: Environmental taxes, externalities, nonseparability, dynamic general equilibrium, structural change.

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1. Introduction

It is well documented that developed countries have experienced sustained growth in the post-war era (Jones and Romer, 2010; Jones, 2015).[1] However, the relationship between economic productivity and environmental quality has been studied much less. Pollution has declined remarkably over the past fifty years—today, it is a third of what it was in 1957. Meanwhile, consumption has continued growing between three and six percent per year. Understanding the factors that generated this joint decline in pollution and rise in consumption is an important issue because it not only influences the types of policies that are likely to promote continued growth, but also sheds light on the important interactions between market and non-market goods through a country's process of structural transformation.

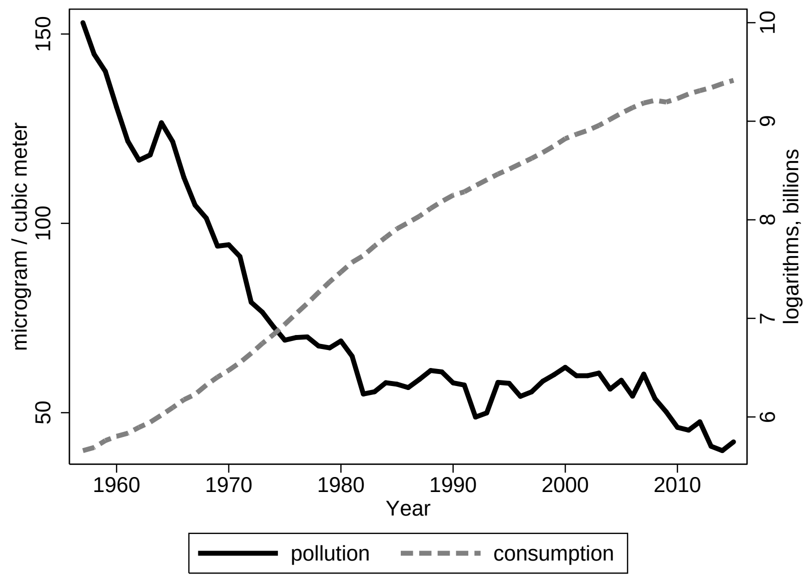

Figure 1: Consumption and Pollution, 1950-2015

Notes.–Source: Bureau of Economic Analysis, and Environmental Protection Agency annual summary files. The figure plots total suspended particulates (TSP) in micrograms per cubic meter averaged across counties (using county population weights) and logged total consumption (in billions).

Pollution and energy intensity have declined, despite the continued rise in energy and non-enregy consumption. Services consumption—in particular, housing and health, which are typically thought of as complements to air quality—have grown especially rapidly (see Figure 2).[2],[3] Although there is some evidence that economic development and environmental quality go hand-in-hand (Grossman and Krueger, 1995),

[1]The broader macroeconomics literature has studied cross-country productivity differentials for many years. Mankiw et al. (1992) was an early empirical contribution testing the neoclassical growth model and extent to which human capital could explain cross-country productivity differences. Klenow and Rodriguez-Clare (1997) offered a contrasting perspective using a different measurement technique for human capital (including secondary schooling). Parente and Prescott (1994) and Parente and Prescott (1993) focused on trade barriers and monopoly distortions across countries. Hall and Jones (1999) focuses on the role of social infrastructure in determining the utilization of capital and labor inputs.

[2]The consumption share of services grew from nearly 40% in 1950 to 70% by the late 2000s. Within the set of services, the consumption shares of housing (health care) grew from 13% in 1950 to just under 20% by the late 2000s (4% in 1950 to 17% by the late 2000s. If, instead, gross output industry-level shares are used, the share of manufacturing output falls from 40% in 1947 to 20% by 2014, whereas services grows from 20% in 1947 to 50% by 2014.

[3]Prior literature has already documented the strong adverse effects of pollution on housing prices (Chay and Greenstone, 2005) and mortality (Chay and Greenstone, 2003; Currie and Neidell, 2005; Greenstone et al., 2013).

these dynamics have been difficult to explain using purely reduced-form methods—that is, relating simple measurements of income and greenhouse gas emissions across countries (Harbaugh et al., 2002; Andreoni and Levinson, 2001). Neither are the current class of macroeconomic growth models equipped to reconcile these facts (e.g., see Hansen and Ohanian (2016) for a survey). This primary contribution of this paper is to build a refinement upon the neoclassical growth model that is capable of explaining these facts and use it to evaluate candidate environmental policies.

The simultaneous decline in pollution and rise in per capita GDP (and consumption) can be attributed to three plausible sources: (i) changes in the composition of goods (e.g., out-sourcing pollution-intensive production), (ii) changes in productivity (e.g., energy efficiency), and (iii) changes in the demand for pollution. While recent empirical evidence from Levinson (2014a) and Shapiro and Walker (2015) argue against composition effects as an important mechanism in the manufacturing sector using *post*-1990 data, whether the decline in pollution *pre*-1990 is driven in part by the structural transformation away from manufacturing is an open question. If structural transformation did play a role, was it driven by supply-side mechanisms (e.g., improved technology) or demand-side mechanisms (e.g., non-homothetic preferences)? The answer is important for policymaking. If, for example, individuals' preferences for air quality increased as their incomes grew, then policies that reduce consumption for improved environmental quality may represent an optimal trade-off. On the other hand, if firms became more productive due to, for example, improved energy efficiency, then policies aimed at raising energy productivity may represent an optimal trade-off. Reconciling these channels is essential for disciplining environmental policy as policymakers debate the costs and benefits of climate proposals. This paper answers these questions by solving and estimating a structural general equlibrium model.

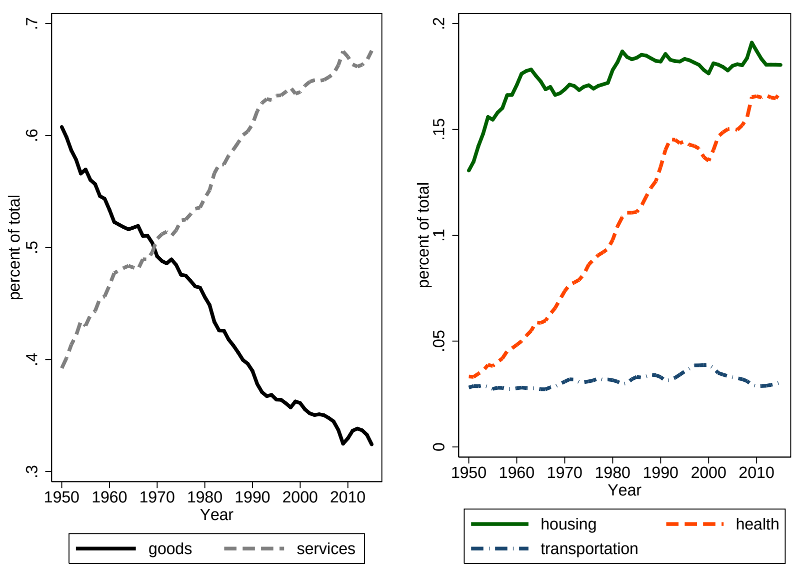

Figure 2: Consumption & Output Shares, 1950-2015

Notes.–Source: Bureau of Economic Analysis, and Environmental Protection Agency annual summary files. The figure plots the consumption shares of goods versus services (relative to the total personal consumption expenditures), as well as housing/utilties, health, and transportation (relative to the total personal consumption expenditures).

The first part of the paper begins by presenting three stylized facts over the 1960-2010 era. First, technological change appears to be biased in favor of energy-savings technologies (over non-energy inputs). For example, using a combination of U.S. KLEMS, IPUMS Higher Ed survey of STEM workers, and the Current Population Survey (CPS), increases in energy R&D and the price of energy are associated with increases in energy productivity measured through wages. Second, energy efficiency has grown dramatically. For example, using the Manufacturing Energy Consumption Survey (MECS), declines in pollution are associated with increases in energy efficiency at the three-digit industry level. Third, preferences for air quality have grown. For example, using the Decennial Census and Environmental Protection Agency (EPA) annual summary files, the conditional correlation between pollution and housing values has grown in magnitude.

The second part of the paper uses the micro-level evidence to motivate a refinement upon the canonical neoclassical model used to understand structural transformation; see, for example, Herrendorf et al. (2014). There are three sectors: manufacturing, services, and energy. Both manufacturing and services produce their own consumption goods using a combination of energy and labor services. Production features both unbalanced (Acemoglu and Guerrieri, 2008) and complementarity between energy and non-energy inputs in the production of final goods (Hassler et al., 2016).[4] Motivated by evidence from Makridis (2014)of non-separability between market and non-market goods—and its quantitative significance in general equilibrium from Carbone and Smith (2008) and Carbone and Smith (2013)—my preferences allow for non-separability between pollution and both consumption goods.[5],[6] The model provides a micro-founded channel for generating structural transformation without imposing non-homothetic preferences from the outset. Since services are less energy intensive than manufacturing goods, the rise of the services sector leads to a decline in pollution, which complements services-based consumption goods (e.g., health care).[7]

After calibrating the model using simulated method of moments (SMM) and using the actual productivity shocks observed in the data, I show that the model matches the central features of the U.S. experience in structural transformation (e.g., relative manufacturing and services consumption shares). Even without unbalanced growth affecting relative prices, the inclusion of non-separability between market and non-market goods provides a micro-foundation behind the Environmental Kuznets Curve (EKC) in Grossman and Krueger (1995) and a complementary channel for generating structural transformation (relative to the existing approaches in Kongsamut et al. (2001), Foellmi and Zweimueller (2006), Ngai and Pissarides (2007), and Herrendorf et al. (2013)). Importantly, including both non-homothetic preferences (through preferences over pollution) and unbalanced growth generates simulated series that match U.S. data, which resolves a

[4]Both of these ingredients are important in the environmental context. For example, Acemoglu et al. (2012) formalize a model of directed technical change and the environment. The most crucial parameter in their setting is the elasticity between clean and dirty inputs, which resembles the elasticity between energy and non-energy inputs in my setting (and in Hassler et al. (2016)).

[5]A number of recent papers have also provided microeconomic evidence about the interactions between non-market goods and individual behavior, including the undertaking of defensive investments (Greenstone et al., 2013), the effects of pollution on infant mortality (Chay and Greenstone, 2003; Currie and Neidell, 2005), labor productivity (Graff Zivin and Neidell, 2012; Hanna and Oliva, 2015), and health and human capital (Moretti and Neidell, 2009; Neidell, 2007; Schlenker and Walker, 2012).

[6]There is a sparse literature on potential non-separabilities between market and non-market goods. Schwartz and Repetto (2000) provided a theoretical treatment of nonseparability, but ignored general equilibrium effects. Williams (2003) suggests that the health benefits of reduced pollution will not have large general equilibrium consequences as a defense for additive separability, but faces some identification problems and does not use micro-data.

[7]There is a large literature on the link between health and pollution. See, for example, Chay and Greenstone (2003), Currie and Neidell (2005), and Currie et al. (2014) for a survey.

challenge posed by Buera and Kaboski (2009) about the current class of models.

The third part of the paper uses the model to conduct several quantitative computational experiments. First, I simulate two counterfactual variants of the model: one with additively separable preferences between the market and non-market goods (but holding fixed the production side) and one with Cobb-Douglas production between labor and energy (but holding fixed the household side). Whereas the former variant shuts down the impact of pollution on the marginal utility of consumption, the latter shuts down the impact that energy-savings technologies have on the relative prices of the two consumption goods. Second, I examine the general equilibrium effects of environmental taxes. These results build on an older literature in environmental economics employing computable general equilibrium (CGE) models, which focused heavily on quantifying how the allocation of environmental tax revenues affected general equilibrium outcomes (Bovenberg and De Mooij, 1994; Bovenberg and Goulder, 1996; Goulder, 1995a). My model also builds on a long list of studies examining the effects of taxes on labor supply and productivity (Prescott, 2004; Ohanian et al., 2008; Rogerson, 2008).[8] My results also provide an alternative approach to quantifying the effects of environmental regulation, most notably the Clean Air Act Amendments on employment (Walker, 2013; Greenstone, 2002) and productivity (Greenstone et al., 2012).

2. Empirical Evidence

2.1. Directed Technical Change

Recent macroeconomic literature has emphasized the role of directed technological change in the skill content of labor services (Krusell et al., 2000; Ohanian and Orak, 2016) and investment (Greenwood et al., 1988; Fisher, 2006). However, an equally important trend has been taking place between energy and non-energy inputs. Energy-savings technologies grew disproportionately over the post-war era, relative to other technological changes. Although there is a developed body of theoretical literature on directed technical change (Acemoglu, 2002, 2007), specifically in the environmental setting (Acemoglu et al., 2012; Gans, 2012), as well as general evidence of price-induced technical change in the energy sector (Popp, 2002; Acemoglu et al., 2012; Calel and Dechezlepretre, 2016), there is sparse empirical evidence on the *relative* technological change between energy and non-energy inputs.

This section provides some motivating evidence on unbalanced growth in favor of energy-savings technologies. A natural starting point for understanding the presence of directed technical change is through a canonical supply and demand framework—that is, by looking at relative quantities and prices in the manufacturing and services sectors for labor and energy inputs. Using sectoral-level KLEMS data assembled by Jorgenson et al. (1987), Figure 3 measures quantities and prices by plotting output and price productivity series, respectively for energy and labor. These are defined by taking the logged difference between output and the respective input for both quantities and prices. While the rise in labor productivity is well-known, due at least in part to rising educational attainment (Goldin and Katz, 2008; Acemoglu and Autor, 2012), the rise of energy productivity is equally as large. Trends between the manufacturing and services sector are

[8]See de Mooij (2000) or Goulder (1995b) for a literature review for a quicker summary.

similar, although the manufacturing sector exhibited greater technological gains, which is consistent with evidence about the technique effect within narrow product categories (Shapiro and Walker, 2015).

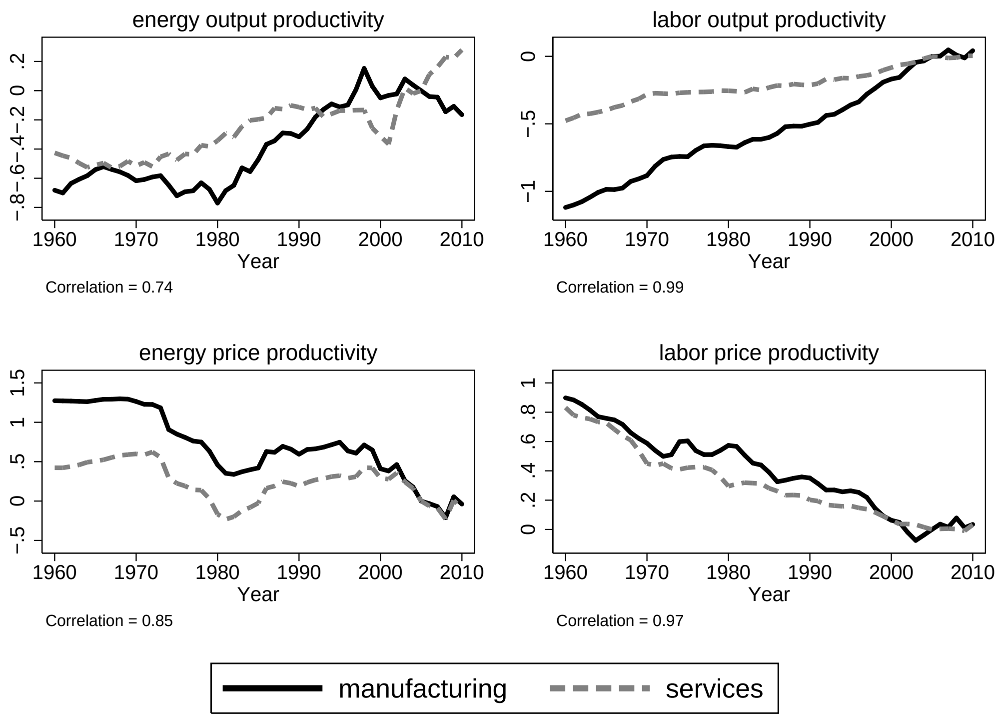

Figure 3: Energy and Labor Output and Price Productivity, 1960-2010

Notes.–Source: Dale Jorgensen KLEMS 32-sector data for the United States. The figures plot energy and labor productivity, Using output and input indices, energy output productivity is defined as logged output net of logged energy, whereas labor output productivity is defined as logged output net of logged labor. Price productivities are defined analogously by using

However, looking purely at the national time series potentially confounds bias in the direction of technical change with other macro-factors. To address this concern, I implement quasi-experimental exercises. The first exercise exploits the passage of the Energy Policy Act (EPACT) on July 29, 2005, which represents one of the most significant energy legislations in the past two decades, providing billions in loan guarantees and other incentives for alternative energy and nuclear power.[9] Using the IPUMS Higher Ed survey between 1993 and 2013, covering individuals educated or employed in a wide array of science, technology, engineering, and mathematics (STEM) fields, I compare earnings among STEM workers in energy-related fields before versus after the passage of EPACT[10]

$$w_{it} = \beta f(X_{it}) + \pi 1[Energy_{it}] + \gamma 1[EPACT_t] + \delta(1[Energy_{it}] \times 1[EPACT_t]) + Year_t + \epsilon_{it} \tag{1}$$

where w denotes logged annual earnings, X denotes a vector of individual covariates, $1[Energy]$ denotes

[9]Specifically, it provided \$4.3 billion to nuclear power, \$2.8 billion to fossil fuel production, \$2.7 billion to renewables through the electricity production credit, \$1.6 billion to clean coal facilities, \$1.3 billion for energy conservation and efficiency, \$1.3 billion for alternative fuels, and \$500 million for the Clean Renewable energy Bonds program.

[10]These surveys are: the National Survey of College Graduates (NSCG), the National Survey of Recent College Graduates (NSRCG), and the Survey of Doctorate Recipients (SDR). While the NSRCG was discontinued after 2010, the other two surveys have continued and cover the entire college graduate population in the United States.

an indicator for the worker being in an "energy job", $1[EPACT]$ denotes an indicator for passage of the energy policy act, and $Year$ denotes a linear year trend. The objective behind Equation 1 is to examine whether the plausibly exogenous passage of R&D for energy technologies led to a rise in the price associated with labor in the energy sector. The second exercise exploits year-to-year changes in the state-level price of gasoline. Using the Current Population Survey (CPS) between 1990 and 2015, I compare earnings among workers in energy-related fields in response to plausibly exogenous shocks in the price of energy

$$w_{it} = \beta f(X_{it}) + \pi 1[Energy_{it}] + \gamma q_{st} + \delta(1[Energy_{it}] \times q_{st}) + \text{Fixed Effects} + \epsilon_{it} \tag{2}$$

where q denotes logged state-level gasoline prices and Fixed Effects denotes a vector of state and occupation fixed effects. The objective behind Equation 2 is similar as before, but now focusing on a broader sample of the labor force (besides scientists / STEM workers).

Table 1 documents both these sets of results. The first two columns report the estimated coefficients from Equation 1. The first column suggests that energy workers earned 8% more in annual earnings after the passage of EPACT, relative to their counterparts. One concern, however, is that these two sets of workers are systematically different. Although there is not a clear rationale for why unobserved heterogeneity would be correlated with the passage of EPACT, the second column adds an array of controls about the underlying activities on-the-job—indicators for whether an individual allocates at least 10% of their time in a particular activity (e.g., personnel issues). Their inclusion only marginally affects the estimated coefficients and, in fact, raises the interaction to 9%.

The last two columns report the estimated coefficients from Equation 2. The first of these columns only contains state fixed effects and a time trend, in addition to the individual covariates. The estimated interaction between state gas prices and energy workers is insignificant. Unobserved heterogeneity in this setting, however, is more plausible since certain sets of workers might be more likely to locate in states with higher versus lower gasoline prices. The second of these columns introduces three-digit occupation fixed effects, comparing energy workers in occupation o with non-energy workers also in occupation o. The estimated coefficient becomes significant and positive, suggesting that a 10% rise in gasoline prices is associated with a .2% rise in earnings for energy workers.

These results are consistent with those from Calel and Dechezlepretre (2016) who exploited the passage of the European Union Emissions Trading Scheme (ETS) and found a 36.2% increase in patenting activity among those regulated firms and those from Aghion et al. (2016) who found that higher fuel prices induce innovation in clean technologies, particularly in areas that have a larger market size. However, unlike prior literature, these results provide evidence on the relative bias of energy-induced technical change over non-energy inputs using wages as a proxy for productivity. These results complement those from Hassler et al. (2016) who found that the rise of energy prices during the 1970s was associated with a rise in R&D.[11]

[11] I also examined several other diagnostics. For example, the growth rate of energy productivity is 25% higher than the growth rate of labor productivity between 1960 and 2015. When looking at other countries in the sample, the wedge between the two growth rates is even stronger: 2.8% for energy productivity growth, on average, versus 1.7% for labor productivity growth.

Table 1: Bias in the Direction of Energy-savings TFP

Dep. var. = logged earnings	NSF	NSF	CPS	CPS
1[energy worker]	.14***	.05***	.22***	.06**
	[.01]	[.01]	[.03]	[.03]
1[EPACT passage]	.10***	.10***		
	[.01]	[.01]		
× 1[energy worker]	.08***	.09***		
	[.01]	[.01]		
logged gas price			.04***	.04***
			[.01]	[.01]
× 1[energy worker]			.01	.02***
			[.01]	[.01]
R-squared	.28	.36	.20	.29
Sample Size	372583	372583	357400	357400
Demographic Controls	Yes	Yes	Yes	Yes
Job Activity Controls	No	Yes	No	No
Occupation FE	No	No	No	Yes
State FE	No	No	Yes	Yes
Year trend	Yes	Yes	Yes	Yes

Notes.–Sources: IPUMS Higher Ed (1993-2013 "NSF"), Current Population Survey (1990-2015 "CPS"), EIA gasoline price series. The first two columns in the table report the coefficients associated with regressions of logged earnings on an indicator for whether the worker is in the energy sector, an indicator for whether the Energy Policy Act of 2005 is in place, their interaction, and controls. Controls include: a year time trend, number of children, age, male, race (white, asian), and education fixed effects (bachelors, masters, PhD, normalized to a professional degree). Controls on job activities are indicators for the following categories: organizational development, design, employee issues, management, other, production, quality, sales, service, teaching, applied research, basic research, computer applications, and supervising. Energy STEM workers are those working as chemists (except bioscientists), chemical engineers, electrical/computer hardware engineers, and civil engineers. Standard errors are clustered at the person-level. The last two columns in the table report the coefficients associated with regressions of logged earnings on an indicator for whether the worker is in the energy sector, logged state-level gasoline prices, their interaction, and controls. Controls include: a quadratic in age, number of children, a quadratic in years of schooling, race (white, black), marital status, and male. Energy workers are those working in one of the following industries: coal/oil/gas extraction, petroleum and coal, machinery and computing equipment, transport equipment, communications, utilities, electrical goods, and petroleum products. Standard errors are clustered at the state-level.

2.2. Rise of the (Energy Efficient) Machines

Both energy intensity and pollution have declined significantly over the past 40 years. Using data from the Energy Information Administration (EIA), Figure 4 plots the ratio of energy to GDP ("energy intensity") and end-use energy intensity, which declined by over a factor of two since 1970.[12] The decline in energy intensity is also associated with a decline in pollution. Figure 5 illustrates that these declines primarily took place within the industrial sector: energy consumption and emissions not only remained relatively constant during periods of significant economic growth, but also began declining in the 1990s, relative to trend. In fact, emissions from the industrial sector declined so much, relative to trend, that the the electricity generating (transportation) sector surpassed it in total carbon emissions production in 1983 (1999).

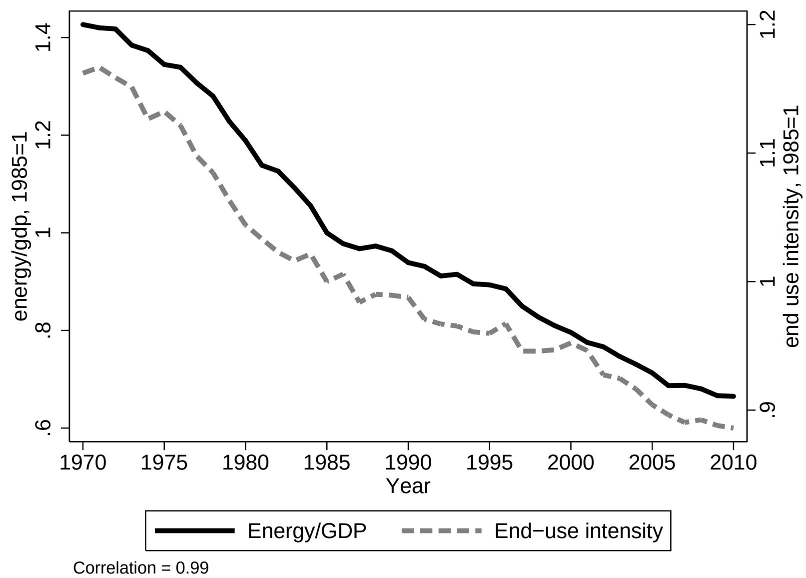

Figure 4: Economy-wide Energy Intensity in the United States, 1970-2010

Notes.–Source: EIA energy efficiency (http://www.eia.gov/consumption/data.cfm). The figure plots the energy to GDP ratio and end-use energy intensity (normalized to 1985 as the base).

Why might have emissions declined so substantially in the industrial ("manufacturing") sector? Recent contributions from Levinson (2014a) and Shapiro and Walker (2015) document the decline in pollution and attribute most of the variation to changes in technique and regulation. Building on their contributions and using the Manufacturing Energy Consumption Survey (MECS), Figure 6 shows that the fraction of establishments participating in energy efficiency programs (e.g., energy audits) grew from under 20% to over 45% by 2010.[13]

Are these increases in energy efficiency programs associated with declines in pollution? Using the EPA annual summary files, I produce an industry-level measure of pollution as follows

[12] The two definitions vary only marginally. End-use energy refers to its final activity that it is used in, such as heating or air conditioning in the case of residential end-use activities, rather than the intermediary processes involved in getting it to its final destination.

[13] Since these are written as a share of overall establishments, the rise does not reflect an increase in the number of manufacturing firms, especially in light of evidence on the decline of U.S. manufacturing due to increasing export competition from China (Autor et al., 2013).

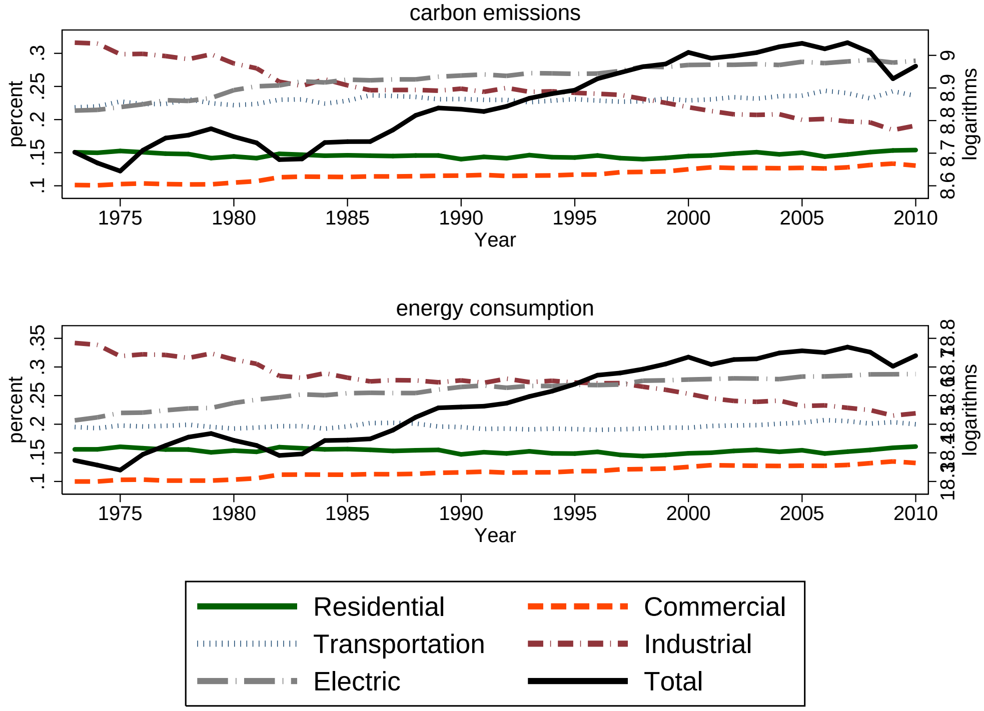

Figure 5: Emissions and Energy Consumption in the United States, 1970-2010
Notes.–Source: EIA energy efficiency and emissions. The figures plot the sectoral carbon emissions (million metric tonnes, each sector as a share of the total) and energy consumption (trillions of btu for energy, each sector as a share of the total).

$$P_{it} = \sum_{i} \left(\frac{EMP_{i,c,t}}{EMP_{i,t}} P_{c,t} \right)$$

where i denotes three-digit manufacturing industries, c denotes the county, and t denotes the year.[14] Using the constructed measure of PM10 pollution, Figure 7 plots the growth in pollution with the growth in participation in energy efficiency programs, producing a significant coefficient of -0.054. The fact that the rise in energy efficiency is associated with declines in pollution even in three-digit manufacturing industries suggests that the rise of energy-savings technologies had an impact.[15]

2.3. Preferences for Non-market Goods

The traditional approach to testing for non-homothetic preferences exploits direct measures of expenditure shares and prices. However, non-market goods, by construction, do not have observable prices. Instead, environmental economists impose restrictions on the equilibrium behavior of asset markets, such as housing and labor markets, to infer individuals' willingness to pay for environmental quality. The basic identifying

[14]Unfortunately, the National Emissions Inventory (NEI) does not have reliable measures of pollution at an SIC or NAICS level, especially for earlier years. Only the most recent 2011 version has detailed NAICS codes.

[15]It is important to put the above evidence on energy-savings technologies in context. For example, Levinson (2014b) and Levinson (2016) examine the effect of residential building codes on electricity consumption, finding that most of the variation arises purely from demographic differences and changes over time. Fowlie et al. (2015) also find that the stated benefits of energy efficiency government audits have been largely over estimated.

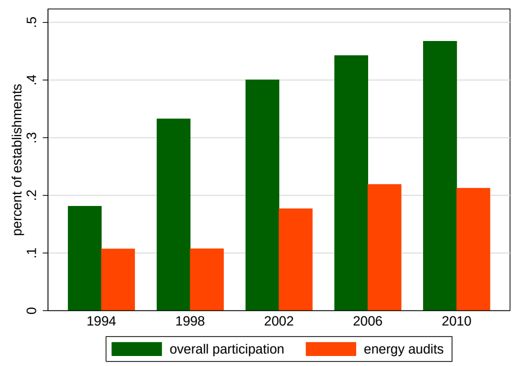

Figure 6: Participation in Energy Efficiency, 1994-2010
Notes.–Source: Energy Information Adminisration's Manufacturing Energy Consumption Survey (MECS). The figure plots the fraction of establishments (pooled across all measured manufacturing industries) that participate in some energy efficiency programs and energy audit programs.

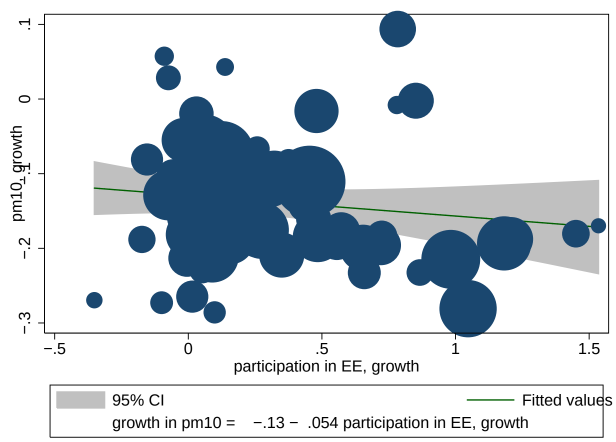

Figure 7: PM10 Pollution and Energy Efficiency
Notes.–Source: Census Bureau's County Business Patterns, Environmental Protection Agency's annual summary files, and Energy Information Adminisration's Manufacturing Energy Consumption Survey (MECS). The figure plots growth in PM10 with the growth in participation in energy efficiency programs at the three-digit industry level weighted by employment.

assumption is that individuals sort into areas based in part on their preferences for non-market goods (Tiebout, 1956), meaning that housing values (Rosen, 1974) and wages (Roback, 1982) can be used to infer the value of local amenities. These hedonic models are typically estimated through regressions of the form

$$h_{ict} = \beta g(X_{ict}) + \gamma P_{ct} + \phi_s + \epsilon_{ict} \tag{3}$$

where h denotes logged housing values for a census tract i, county c, and period t, X denotes time-varying demographic covariates, P denotes pollution, and ϕ are fixed effects on state, which avoid potentially erroneous comparisons between locations with systematically different economic outcomes.[16]

Using 40 years of micro-data from the Census Bureau, accessed through SocialExplorer, I estimate Equation 3 separately by decade to examine the potential change in tastes for air quality. I control semiparametrically for a number of demographic features, including the fraction of households within each tract that are

[16]The estimated $\hat{\gamma}$'s may lack a causal interpretation and/or only represent a capitalization effect (Kuminoff and Pope, 2014).

between 0-17 years old, 18-35, 35-44, 44-65, and over 65, the fraction of households that are black, white, married, male, and have a college degree. I also control for the fraction of workers who are employed and for the logged population of the area. Pollution is measured using ozone emissions in parts per million accessed through the Environmental Protection Agency's annual summary files.

Figure 8 plots the estimated $\hat{\gamma}$'s separately by year to proxy for the price of pollution. Although housing values and pollution were not statistically associated with each other between 1970 and 1980, the estimated coefficient declines significantly in magnitude starting in 1990 and especially by 2000: a unit rise in pollution is associated with a large 0.6% decline in housing values ($= 15 \times 0.04$ where 0.04 is the mean pollution level) in 2000. The estimated coefficients decline in magnitude between 2005 and 2010, but remain robustly negative. The fact that the conditional correlation between pollution and housing values declines is consistent with non-homothetic preferences whereby tastes for air quality rise as incomes and other consumption services complementary with air quality rise (e.g., health care).

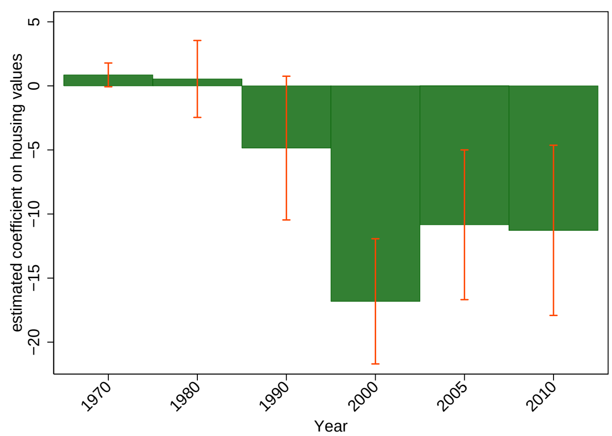

Figure 8: Preferences over Environmental Quality, 1970-2014
Notes.–Source: Census Bureau (through Social Explorer) and Environmental Protection Agency summary files. The figures plot the estimated hedonic capitalization effects associated with the coefficients of logged ozone pollution from regressions of logged housing values on logged ozone, conditional on the fraction of people within each tract in different age bins (0-17, 18-35, 35-44, 44-65, and 65+), race (white/black), male, married, logged population, the fraction of college workers, and the employment rate. While the coefficients are estimated separately by year, each regression contains state fixed effects. Pollution is measured as ozone in parts per million. Standard errors are clustered at the county-level.

2.4. Other Issues

There are a number of additional issues examined in the Appendix. The first is cross-country evidence on the decline in pollution intensity and energy productivity. Although there are some exceptions (e.g., Spain), these trends in the U.S. are pervasive across OECD economies. The second is endogenous technological change with models based on monopolistic competition. Although these models are important heuristics for understanding innovation, the bulk of the structural transformation literature takes technology trends as exogenous and uses calibrated series to simulate models forward. The third is the elasticity of substitution between energy and non-energy inputs. The elasticity matters greatly; see, for example, Acemoglu et al. (2012) and Hassler et al. (2016). Papageorgiou et al. (2016) has provided some recent empirical evidence on plausible elasticity values by estimating cross-country production functions, but endogeneity of factor inputs remains an empirical challenge.

3. Quantitative Model

3.1. The Environment

3.1.1. Preferences

Time is discrete, denoted by $t = 1, 2, ..., \infty$. There is a representative household consisting of a continuum of intertemporally optimizing dynastic individuals of measure one. Preferences exist over consumption (C), leisure ($1 - N$), and pollution (P) given by

$$U(C_t, L_t; P_t) = \log C_t + \alpha \frac{(1-N_t)^{1-\psi}}{1-\psi} \tag{4}$$

where α denotes the relative weight of leisure over consumption, ψ denotes the intertemporal elasticity of substitution for quality-adjusted labor supply, and aggregate consumption is given by a constant elasticity of substitution between manufacturing consumption, denoted C_M, and services consumption, denoted C_S

$$C_t = \left[\omega \tilde{C}_{M,t}^{\sigma} + (1-\omega)\tilde{C}_{S,t}^{\sigma}\right]^{1/\sigma}$$

where ω is the distribution parameter on both quality-adjusted consumption goods, σ is the elasticity of substitution, and each consumption good is affected by the level of pollution in the economy

$$\tilde{C}_{i,t} = \left[\pi_i C_{i,t}^{\eta_i} + (1-\pi_i) P_t^{-\eta_i}\right]^{1/\eta_i}, \quad i \in \{M, S\}$$

where π_i is the relative distribution parameter for consumption good i and η_i is the elasticity of substitution between consumption and air quality, denoted as the inverse of pollution (i.e., $1/P$) to capture the fact that higher levels of pollution adversely affect utility.

These preferences have three main advantages. First, they allow for environmental quality to interact non-separably with both consumption and leisure, nesting the case of additive separability, and focus the attention on dynamic emerging from non-separability with the externality, rather thant consumption-leisure dynamics. Second, they are consistent with the wide body of macroeconomic evidence of balanced growth (Long and Plosser, 1983; King et al., 1988; Kydland and Prescott, 1982) since these preferences are simply a modification of consumption and leisure such that they are adjusted for environmental quality.[17] Third, environmental quality, proxied through pollution, makes preferences non-homothetic since individuals take it as given when optimizing over consumption and leisure. Non-homothetic preferences have been highlighted as important mechanisms for explaining structural change (Herrendorf et al., 2014; Boppart, 2014) and the

[17] Although there is evidence of nonseparability between consumption and leisure at the micro-level, a wide body of empirical papers have been unable to detect any meaningful predictable variation in hours that is related with predictable variation in consumption (Eichenbaum et al., 1988; Campbell and Mankiw, 1989, 1990).

demand for air quality (Makridis, 2014; Smith, 2012).

Households maximize discounted utility, choosing $\{C_{M,t}, C_{S,t}, N_t\}_{t=0}^{\infty}$, subject to the two consumption constraints and the budget constraint that expenditures equal labor income

$$q_{M,t}C_{M,t} + q_{S,t}C_{S,t} = w_t N_t(1-\tau_t) + T_t \tag{5}$$

where $q_M = 1$ is the normalization on the price of consumption and T denotes lump sum transfers back to households based on the government's tax revenue. The budget constraint can be manipulated into the following form

$$1 - N_t = \left[1 - \frac{C_{M,t} + q_{S,t}C_{S,t} - T_t}{w_t(1-\tau)}\right]$$

which can be substituted into preferences in order to optimize the objective function with respect to just C_M and C_S. Doing so produces two intra-temporal Euler conditions that relative relative prices with consumption of the corresponding goods.

While similar to the literature on structural change that tends to implement multi-sector general equilibrium models, the model presented here features energy and abatement intermediate firms, rather than multiple goods-producing sectors as in Stefanski (2014). The model here allows for an income elasticity below unity and substitutability between consumption and air quality, thereby generating structural change motivated from demand-side factors; these ingredients are not present in Stefanski (2014).

3.1.2. Technology

Suppose that each of the two consumption-producing sectors have constant elasticity of substitution production functions. Since there are no savings in the economy, consumption equals output in both sectors

$$C_{i,t} = A_{i,t}\left[\chi_i N_{i,t}^{\nu_i} + (1-\chi_i)E_{i,t}^{\nu_i}\right]^{1/\nu_i}, \quad i \in \{M, S\} \tag{6}$$

Each sector uses a combination of labor services and energy. However, energy is an intermediate good, which is also produced using labor services, given by the following Cobb-Douglas function

$$E_t = A_{E,t}N_{E,t}^{\theta_E} \tag{7}$$

Total energy is the sum of sectoral energy

$$E_t = E_{M,t} + E_{S,t} \tag{8}$$

which produces pollution at a linear rate[18]

$$P = \xi E \tag{9}$$

[18]These concentration-response function (CRF) are commonly applied in health economics and natural sciences to link physical emissions with mortality risk (Pope et al., 2002).

Markets are perfectly competitive, meaning that each firm maximizes its profits subject to its technology constraint, producing the following first-order conditions for relative prices

$$w_t = q_{i,t} A_{i,t} \left[\chi_i N_{it}^{\nu_i} + (1-\chi_i) E_{i,t}^{\nu_i}\right]^{\frac{1-\nu_i}{\nu_i}} \chi_i N_{i,t}^{\nu_i - 1}, \quad i \in \{M, S\} \tag{10}$$

$$q_{E,t} = q_{i,t} A_{i,t} \left[\chi_i N_{it}^{\nu_i} + (1-\chi_i) E_{i,t}^{\nu_i}\right]^{\frac{1-\nu_i}{\nu_i}} (1-\chi_i) E_t^{\nu_i - 1}, \quad i \in \{M, S\} \tag{11}$$

$$w = q_E \theta_E A_{E,t} N_{E,t}^{\theta_E - 1} \tag{12}$$

Since the price of labor is the same across sectors, it is precisely the demand for different goods that determines the demand for labor and, therefore, the allocation of time within the household. Put together, there are twelve equations and twelve unknowns.

Definition 1. *The competitive equilibrium is a set of aggregate quantities for households,* $\{C_{M,t}, C_{S,t}, N_t\}$*, firms,* $\{N_{M,t}, N_{S,t}, E_{M,t}, E_{S,t}\}$*, market prices,* $\{w_t, q_t\}$*, and stochastic growth rates,* $\{A_{M,t}, A_{S,t}, A_{E,t}\}$*, such that* $\{C_{M,t}, C_{S,t}, N_t\}$ *solve the Household Problem,* $\{N_{M,t}, N_{S,t}, E_{M,t}, E_{S,t}\}$ *solve the Producer Problem, the government balances its budget constraint, and markets clear at prices* $\{w_t, q_t\}$*.*

3.2. Model Solution and Calibration

The model is solved using a combination of SNOPT (to first obtain initial conditions) and Matlab (to implement SMM and simulate) using fmincon, together with an analytical jacobian for the deterministic equilibrium. Calibration proceeds in the usual two steps. The first step involves setting a subset of the parameters that are not model-specific (e.g., depreciation rate) to values from prior literature. The following parameters can be calibrated using the national accounts data. Let $\chi_M = 0.8225$ and $\chi_S = 0.9685$ by taking the ratio of energy expenditures to the sum of energy expenditures and value added in the $i(i \in \{M, S\})$-th sector using the U.S. KLEMS data from Jorgensen.[19] The Cobb-Douglas production elasticity on labor among energy producing firms is set to $\theta_E = 0.22$ to match the share of employee (labor) compensation to gross output. Let $\sigma = -0.176$ govern the elasticity of substitution between manufacturing and services consumption, i.e., $1/(1-\sigma)$, based on estimates from Herrendorf et al. (2013). The distribution parameter on manufacturing versus services consumption, ω, is identified by taking the mean ratio of output in the manufacturing sector as a share of manufacturing and services output.

The distribution parameters within (environmental) quality-adjusted manufacturing and services consumption, π_M and π_S, are identified by the Bureau of Economic Analysis' personal consumption expenditures per capita (deflated to real 2009 dollars) through linear regressions of logged consumption (in goods

[19] Manufacturing industries include: food products / beverages and tobacco, textiles / textile products / leather and footwear, wood and products of wood and cork, pulp / paper / paper products / printing and publishing, chemical / rubber / plastics / fuel products, basic metals and fabricated metal products / electrical and optical equipment, transport equipment, manufacturing NEC, recycling. Services industries include: financial intermediation, real estate / renting / business activities, education, health / social work, and other community and social / personal services.

and services) on logged pollution.[20] While there are several plausible pollutants to choose from, particulate matter of 10 microns or less behaves as the baseline since it is regulated under the Clean Air Act Amendments and has the most comprehensive time series information out of the alternatives. The implied coefficients are -0.133 and -0.258 for manufacturing and services consumption, respectively, which are precisely estimated with t-statistics above 4. The identifying assumption is that households non-randomly sort into areas, thereby allowing me to infer their marginal valuation through the capitalization effect of pollution.[21]

The second step involves internally calibrating the remaining parameters, which are done using simulated method of moments (SMM) and indirect inference (Gourieroux and Monfort, 1996; Gourieroux et al., 1993). The parameters are estimated using a minimum distance estimator such that the parameter vector yields simulated moments that best match the data. [22] The following parameters are internally calibrated based on the following guesses $\psi = 2$ (from Keane and Rogerson (2012)), $\alpha = 0.40$ (from Prescott (2004)), $\eta_M = 0.60$ and $\eta_S = -0.60$ (a guess), $\nu_M = -0.50$ and $\nu_S = -0.20$ (a guess), and $\xi = 0.60$ (emissions per GDP)

$$\Theta_I = \{\eta_M, \eta_S, \psi, \alpha, \nu_M, \nu_S, \xi\}$$

The following describes the moments used to identify the internally calibrated parameters using sectoral data between 1960-2010. The elasticities of substitution between manufacturing and services consumption and pollution, η_M and η_S, are identified by their correlations with pollution, which are -0.70 and -0.64, respectively. The elasticity of labor supply, ψ, is identified by the fraction of time allocated towards market services, which is 0.358 on average between 1960 and 2010.[23] The relative weight of consumption versus leisure, α, is identified by their correlation, which is 0.69. The elasticities of substitution between energy and labor in the sectoral production functions, ν_M and ν_S, are identified by the correlations between their correlations with gross output (e.g., the correlations between average share of hours worked and energy with gross output), which are -0.57 and 0.89 for the manufacturing sector and -0.70 and 0.98 for the services sector. Lastly, re-arrange the total factor productivity terms and calibrate them such that

$$A_{it} = C_{it} / \left[\chi_i N_{i,t}^{\nu_i} + (1 - \chi_i) E_{i,t}^{\nu_i}\right]^{1/\nu_i}, \quad A_{E,t} = E_t N_{E,t}^{-\theta_E}$$

where A is chosen so that the first period value is equal to one. However, since the TFP terms cannot be constructed absent value for the two ν_i's, which are part of the internal calibration, the TFP series is re-computed under each iteration of the simulated method of moments.

[20]Goods include: motor vehicles and parts, furnishing and durable housing equipment, recreational goods and vehicles, other durables, food and beverages, clothing and footwear, gasoline and other energy goods, other non-durable goods. Services include: housing and utilities, health care, transportation services, recreation services, food and accommodation, financial services and insurance, and other services.

[21]Handbury and Weinstein (2014) provides microeconomic evidence about prices and consumption amenities in larger versus smaller cities. The approach for computing these value shares follows conceptually from Carbone and Smith (2008).

[22]Letting Ψ^A denote actual moments in the data, and Ψ^S denote simulated moments from the model, then $\vartheta \in \Theta$ is solved by searching over the parameter space to find a parameter vector minimizing the criterion function

$$\hat{\vartheta} = \arg\min_{\vartheta \in \Theta} \left[\Psi^A - \Psi^S(\vartheta)\right]^T \Lambda \left[\Psi^A - \Psi^S(\vartheta)\right]$$

[23]The fraction is obtained by taking total average hours worked/year divided by 5110, which is the normalized hours available allocated to work (after netting out home production and personal time).

Panel A: Moments								
	$Corr(C_M, P)$	$Corr(C_S, P)$	N	$Corr(C, L)$	$Corr(N_m, P)$	$Corr(E_M, P)$	$Corr(N_S, P)$	$Corr(E_S, P)$
Model	-0.64	-0.62	0.35	0.68	-0.66	0.87	-0.64	0.99
Data	-0.70	-0.64	0.35	0.69	-0.57	0.89	-0.70	0.98
Panel B: Parameters								
	η_M	η_S	ψ	α	ν_M	ν_S		.
	0.1372	-1.12	1.34	0.65	0.288	-0.515		

Table 2: Summary of Calibration

Notes.–Source: The table plots the simulated / actual moments in Panel A and the estimated parameters in Panel B (ν_i has two moments that identify it). C_i denotes consumption in sector i (manufacturing and services), P denotes pollution, N denotes the share of time allocated to work, L denotes the share of time allocated to leisure, E_i denotes energy in sector i.

4. Understanding the Decline in Pollution

4.1. Comparing the Model to the Data, 1970-2010

The preliminary model does a fairly good job matching the core features of the data. Figure 9 plots the simulated and actual time series for several of the endogenous variables. The model underpredicts consumption and energy in the services sector, and it has a noisy prediction of manufacturing consumption. However, it has a near perfect fit for energy in the manufacturing sector.

The main source of the gap between the model and data so far is the equivalence between output and consumption. Since pollution and consumption are negatively correlated, but output is producing using energy, which is positively correlated with output, then the two moments are tough to jointly match.

4.2. Decomposition of Structural Change

5. Policy Experiments

5.1. Permanent Environmental Taxes

Suppose that an environmental tax rate of $\tau_d \in (0, 1)$ is introduced on pollution, ξE, which affects the profit maximizing decision of the energy sector. The quantitative model emphasizes two competing channels in general equilibrium. The first is a demand-side mechanism. Since pollution affects the marginal utility of consumption, especially services, declines in pollution can raise welfare and offset the decline in production. Much like the mechanism in Hall and Jones (2007) with non-homothetic preferences over health, at a certain point, the representative agent can become saturated with services consumption and prefer greater air quality. The second is a supply-side mechanism. Since energy and non-energy inputs are imperfect substitutes, environmental policy is costly. In particular, more expensive energy production can raise the cost of consumption and lower welfare.

To approximate the two different demand and supply effects, I simulate two counterfactual economies: one where pollution enters preferences in an additively separable way (e.g., it does not affect the decentralized equilibrium), and the other where energy and non-energy inputs are relative substitutes in production via

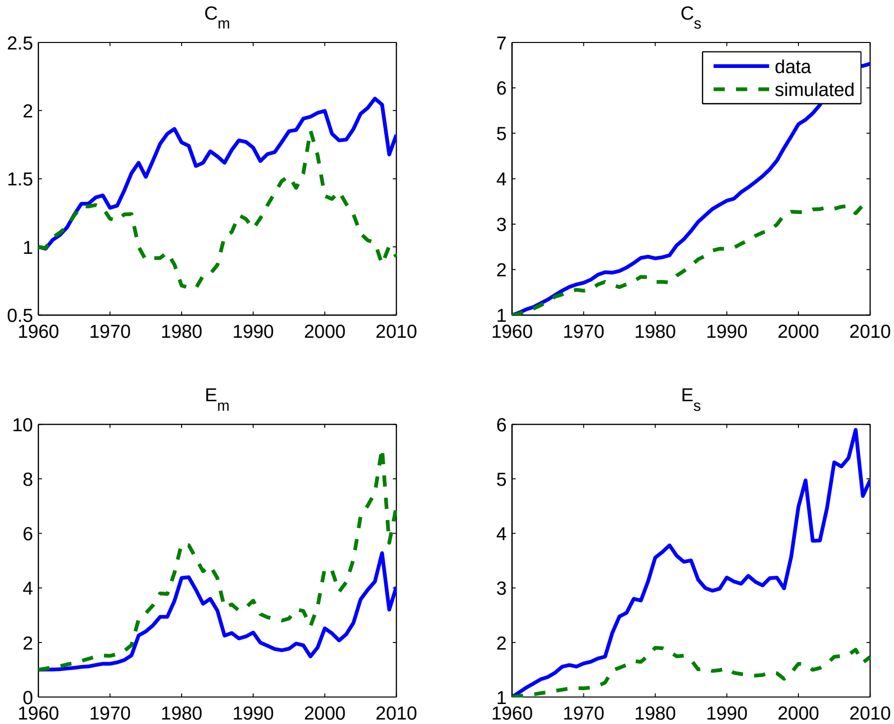

Figure 9: Simulated and Actual Time Series, United States 1960-2010

Notes.–Source: U.S. National Accounts (Bureau of Economic Analysis, Bureau of Labor Statistics, and Energy Information Administration). The plot shows the simulated (perfect forsight) values starting from a steady state calibrated to match the U.S. 1970-2010 period with the actual values during the period.

a more standard Cobb-Douglas production function. Using these two counterfactual economies, and given an environmental tax rate, I can compute the resulting steady states and compare them with the baseline steady state. To facilitate the comparison, define the total effect as the sum of the absolute value of both the wedges discussed above.

$$TE = [|SS(AddSep) - SS(Benchmark)]\,| + [|SS(CobbDoug) - SS(Benchmark)|]$$

The demand-side effects can be approximated via $[SS(AddSep) - SS(Benchmark)]/TE$, denoted DE, and the supply-side effects can be approximated via $[SS(CobbDoug) - SS(Benchmark)]/TE$, denoted SE.[24] Figure 10 documents these results.

5.2. Temporary Environmental Taxes

TBD

[24]By dividing by the total (net) effect, effects are normalized by the benchmark such that the sum of both effects, for a fixed τ_d, is equal to unity.

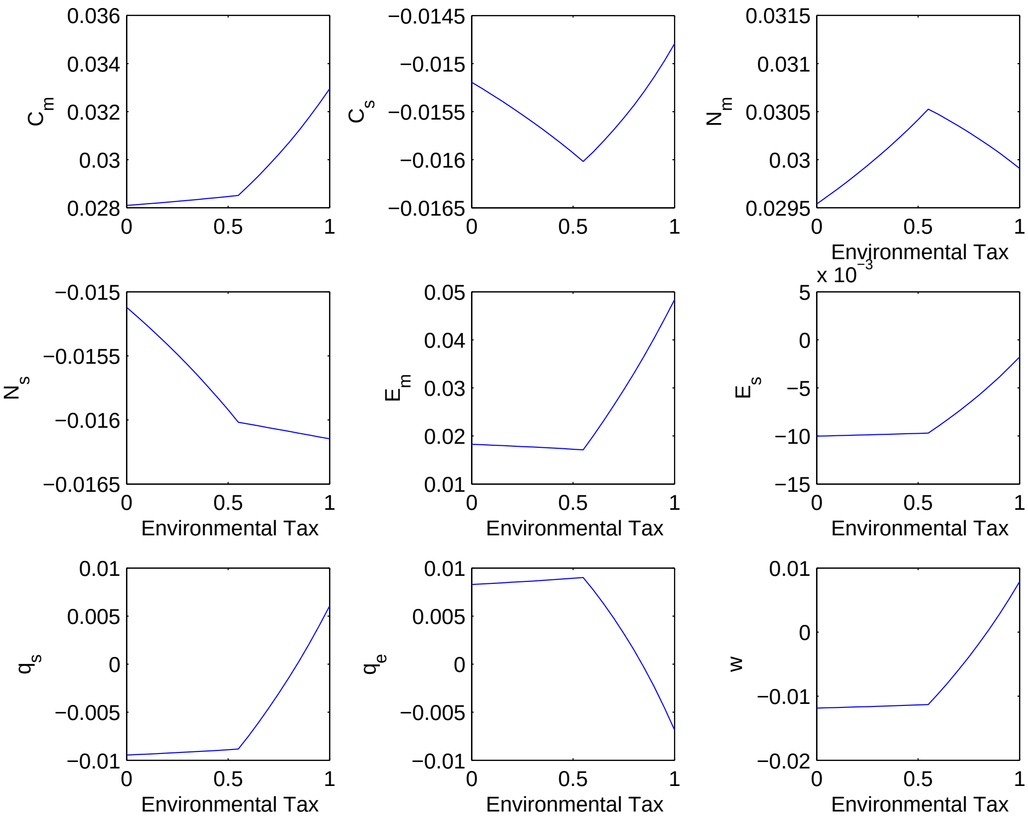

Figure 10: Decomposition of the Demand and Supply Channels

Notes.–The figure plots the demand and supply channels of environmental policy. These channels are defined as follows Denoting the total effect, $TE = [|SS(AddSep) - SS(Benchmark)|\,| + [|SS(CobbDoug) - SS(Benchmark)|]$, the demand and supply side effects are $DE = [SS(AddSep) - SS(Benchmark)]/TE$ and $SE = [SS(CobbDoug) - SS(Benchmark)]/TE$, respectively.

5.3. Implications for Optimal Taxation

Theoretical research on optimal environmental taxes have emphasized the importance of accounting for pre-existing tax distortions (Bovenberg and De Mooij, 1994) and environmental irreversabilities (Cai et al., 2016).[25] In a similar results, the results so far underscore the interaction between non-market and market amenities over the long run. For example, high levels of pollution can undermine health, affecting infant mortality (Chay and Greenstone, 2003; Currie and Neidell, 2005), housing assets (Chay and Greenstone, 2005), and even human capital accumulation (Currie et al., 2014). Given the baseline preferences in my quantitative model, marginal damages are given by $\partial U/\partial P$.[26]

6. Conclusion

Recent models of structural transformation have produced incredible insights in understanding the fundamental sources of changing industrial composition, emphasizing the role of income effects (Kongsamut et al.,

[25] See Golosov et al. (2014) and Barrage (2014) for alternative modeling frameworks.

[26] Metcalf (2009) provides an eloquent summary of the main lessons from the past decade and acknowledges that the optimal tax need not equal or be above marginal damages as early double dividend literature suggested.

2001) and price effects (Ngai and Pissarides, 2007). However, combining income and price effects together jointly in a general equilibrium model has proved difficult in matching the basic U.S. growth facts (Buera and Kaboski, 2009, 2012). The environment has been conspicuously absent from these models. Pollution fell by 70% between 1960 and 2010, while real consumption continued to grow rapidly.

The primary contribution of this paper is to embed preferences for non-market goods (i.e., pollution) into a model of structural transformation to help connect income and price effects and analyze their relative contributions to the decline in manufacturing and rise in services. The first part of the paper provides descriptive evidence on the presence of unbalanced growth in favor of energy-savings technologies, like energy efficiency, and time-varying tastes for air quality. For example, using the Manufacturing Energy Consumption Survey (MECS), I show that sectors that experienced increases in energy efficiency audits exhibited declines in pollution. Similarly, using the Decennial Census from 1970 to 2010, I show that the gradient of pollution on housing strengthened dramatically during the 1980s, suggesting that tastes for air quality grew. Both these documented facts are consistent with the rise of the service sector, which is less energy-intensive and produces consumption that is complementary with air quality (e.g., housing and health services).

The second part of the paper develops a structural model with manufacturing, services, and energy sectors, time-varying productivity growth, and non-homothetic preferences over the environment. Technological change in the services sector affects the price of services, relative to manufacturing. As the economy begins transitioning away from manufacturing goods, pollution declines and raises the marginal utility of services, which accelerates structural change. Whereas existing literature analyzing the decline in pollution in the manufacturing sector has focused on post-1990 outcomes (Levinson, 2014a; Shapiro and Walker, 2015), my model focuses more heavily on pre-1990 outcomes. My results suggest that the bulk of the decline in pollution pre-1990 are accounted for by technological changes, in particular the composition of manufacturing. The third part of the paper (ongoing) uses the model to evaluate the effects of permanent and temporary environmental taxes.

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