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INDUSTRIAL PRODUCTIVITY IN A HOTTER WORLD:
THE AGGREGATE IMPLICATIONS OF HETEROGENEOUS FIRM INVESTMENT IN AIR CONDITIONING

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ABSTRACT

How will a nation's aggregate urban productivity be affected by climate change? The joint distribution of climate conditions and economic activity across a nation's cities will together determine industrial average exposure to climate risk. Air conditioning (AC) can greatly reduce this heat exposure. We develop a simple model of air conditioning adoption by heterogeneous firms within an industry. Our analysis suggests that high productivity firms are more likely to adopt AC since they suffer larger productivity losses when it is hot. Given that the most productive firms produce a disproportionate share of industry-level output, we present aggregation results highlighting how the industry's output is insulated from the heat. Our empirical analysis of the impacts of heat on total factor productivity in U.S manufacturing yields findings broadly consistent with our model's predictions.

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I. Introduction

Temperatures above the human comfort zone can cause fatigue, loss of focus, and even cognitive impairment, all of which can diminish one's workplace performance. Indeed, a wide range of studies have found a negative relationship between temperature and worker performance as temperatures begin to exceed 75 degrees Fahrenheit (e.g. Ramsey, 1995; Seppanen et al., 2004; Hancock et al., 2007; Adharvyu et al., 2014). Recent economic studies that have exploited quasi-experimental variation in temperature exposure have documented similar results at a national scale (Deryugina and Hsiang 2014, Graff Zivin and Neidell 2014) and cross-national scale (Hsiang, 2010; Dell et al., 2012; Heal and Park, 2013). Thus, absent effective adaptation strategies, climate change is expected to significantly reduce labor productivity.

One adaptation strategy for coping with increased heat is to adopt air conditioning. Residential air conditioning adoption has been shown to greatly reduce heat-induced mortality and to increase quality of life in hot humid places (Barecca et al., 2015; Barreca et al. 2016, Biddle 2008, Deschenes and Greenstone 2011, Oi 1996). Evidence on the industrial side suggests that productivity impacts are concentrated in industries and countries that are least likely to have adopted climate control technologies (Graff Zivin and Neidell, 2014 and Heal and Park, 2013, respectively). That poorer countries experience a larger negative marginal effect of heat on macroeconomic performance is also consistent with the notion that access to cooling infrastructure may play an important role in adaptation to climate change (Dell et al., 2013).

Indeed, government officials in nations close to the equator are well aware of the challenges their nations face. Singapore's founding father Lee Kuan Yew was asked what the keys were to Singapore's fast economic growth over the last 50 years. He replied, "Air conditioning was a most important invention for us…. It changed the nature of civilization by making development possible in the tropics. Without air conditioning you can work only in the cool early-morning hours or at dusk."[1]

[1] http://www.vox.com/2015/3/23/8278085/singapore-lee-kuan-yew-air-conditioning

The Singapore case highlights the potential for costly air conditioning (AC) to insulate certain economic sectors from exposure to heat. The degree to which firms adapt to climate change by adopting air conditioning has macroeconomic consequences.

How will a nation's aggregate urban productivity be affected by climate change? The joint distribution of climate conditions and economic activity across a nation's cities will together determine industrial average exposure to climate risk. Such risks will change over time as this joint distribution evolves. Conditional on a firm's locational choice, a firm can invest in air conditioning to offset heat exposure. When a firm invests in air conditioning it incurs a fixed cost of installation and an operating cost of purchasing energy to generate these cooling services. A profit maximizing firm will tradeoff any gains from adopting air conditioning against these costs.

In this paper, we develop a simple model of air conditioning adoption by heterogeneous firms. The modern IO literature has focused on studying the causes and consequences of within industry firm heterogeneity (see Syverson 2011, Davis and Haltiwanger 1994, Davis, Haltiwanger and Shuh 2004). This within industry heterogeneity is important because firm-level productivity influences the benefits from AC adoption. In particular, we show that high productivity firms are more likely to adopt AC since they suffer larger productivity losses when it is hot. As the climate warms, some firms in the middle of the productivity distribution will find it optimal to adopt AC and will no longer be impacted by temperature extremes. At the same time, low-productivity firms will persist without air conditioning and thus suffer under climate change, while high-productivity firms remain unaffected by climate since they already adopted AC.

Since firms at the higher end of the productivity distribution account for a disproportionate share of industry-level output, and those are precisely the firms mostly likely to insulate themselves from ambient temperatures, the macroeconomic effects of climate change will be smaller than a naïve model of adaptation might predict. As in Gabaix (2011), shocks to large firms (or in our case the absence of those shocks) play an oversized role in determining aggregated economic impacts. Our key insight is that air conditioning adoption is not orthogonal to fundamental productivity parameters and thus a proper accounting of the impacts of climate change on industrial output requires additional information on the distribution of firm types within an industry.

We then extend this model to allow workers to treat air conditioning as a workplace amenity, such that in the hedonic compensating differentials equilibrium, firms without air conditioning must pay higher wages (Rosen 2002). In this case, the results from our simple model are strengthened. More firms adopt air conditioning, adaptation to climate change is larger, and the impacts of climate change on the macro-economy is more muted.

The theoretical work is followed by an empirical analysis of the impacts of temperature on the manufacturing sector within the US. Our focus on manufacturing is partly driven by practical concerns about data availability, but also because this is the sector in which we expect to see the most action in terms of AC adoption. It is a *marginal sector* in the US, where air conditioning penetration is neither infeasible (e.g. agriculture and construction) or nearly complete (e.g. office work). As predicted by theory, our industry-level regressions show increased AC usage in response to greater temperature exposure and no aggregate impacts on TFP within manufacturing.

These manufacturing results are particularly interesting because manufacturing is an increasing share of GDP in lower-middle income nations (see Figure 1 based on the World Bank's WDI data), where falling hardware prices and reliable electricity supplies are making AC adoption increasingly feasible.[2]

The paper is organized as follows. Section II presents our basic theoretical model along with some extensions. Section III is focused on our empirical exercise. Concluding remarks are made in Section IV.

II. The Firm's Joint Air Conditioning and Labor Demand Decision

In this section, we develop a model of the air conditioning investment decision in an industry with heterogeneous firms and homogenous workers. In particular, we assume that firms exogenously differ along one dimension, such that each firm has a productivity parameter called θ whereby firms produce more output (holding inputs constant) if they are endowed with a higher θ. Syverson (2011) documents the existence of firm heterogeneity even within narrowly defined industries.

[2] See Davis and Gertler (2015) for evidence of residential AC adoption in LDCs.

Given microeconomic evidence on the relationship between heat and labor productivity (Heal and Park, 2013; Graff Zivin and Neidell, 2014; Adharvyu et al., 2014), we assume that the firm's productivity is decreasing in cooling degree days, a measure of temperature utilized by electric utilities to assess energy demands for air conditioning.[3] In particular, we use a transformed measure of heat (H) that lies between 0 and 1 to reflect the percentage reduction in productivity. Thus, a firm with productivity parameter θ equal to .8 that faces heat H equal to 0.5 will have a productivity level of 0.4.

For simplicity, we assume that air conditioning can completely eliminate the productivity effect from heat. The costs of air conditioning include an upfront fixed cost in hardware, denoted F, and variables costs due to energy consumption from running the equipment, denoted E. The costs of energy are assumed to be convex in heat and independent of firm size such that hiring additional workers does not mechanically change air conditioning expenditure.[4]

II.A. Air Conditioning as a Pure Investment

Let subscript A denote firms that do not adopt air conditioning and thus operate a workplace at <u>ambient</u> temperatures. Similarly, let C denote firms that operate <u>cooled</u> workplaces as a result of air conditioning adoption. Profits for each can be expressed as follows:

$$\pi_A = p \cdot \theta(1 - H){L_A}^{\alpha} - wL_A \tag{1}$$
$$\pi_C = p \cdot \theta {L_C}^{\alpha} - wL_C - F - E(H), \tag{2}$$

where P denotes output prices, L_A denotes labor hired by firms without air conditioning, L_C denotes labor hired by firms with air conditioning, and α is less than 1 such that there is decreasing marginal productivity of labor.[5]

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[3] Cooling degree days (CDD) is a measure of the number of degrees by which the average temperature in a given day exceeded 65 degrees Fahrenheit. For example, a day with an average temperature of 80 degrees corresponds to 15 CDD and a day with an average temperature of 50 degrees corresponds to 0 CDD.

4 Note that scale independence is an assumption of convenience that can be readily relaxed but which complicates interpretation since more firms will now need to consider the output gained from one additional worker against the (potential) increased costs of air conditioning. In practice, the additional air conditioning costs for any worker on the margin will be very small.

5 We recognize that an alternative way to introduce heat exposure is to model it as scaling down the effective quantity of labor that the firm can use. We present the multiplicative structure because it simplifies the algebra. In

The first order condition for each type of firm are as follows:

$$\frac{\partial \pi_A}{\partial L_A}|_{L_A=\hat{L}_A} = \alpha p \theta (1-H) \hat{L}_A^{\alpha-1} - w = 0 \tag{3}$$

$$\frac{\partial \pi_C}{\partial L_C}|_{L_C=\hat{L}_C} = \alpha p \theta \hat{L}_C^{\alpha-1} - w = 0 \tag{4}$$

where $\hat{L}$ denotes the optimal choice of labor for each type of firm. Firms hire labor such that the marginal value product of labor is equal to the wage. Since wages are identical for either type of firm (an assumption we will relax in the next section) and labor is more productive in cooled firms, those firms that find it optimal to adopt AC will hire more labor. Indeed, combining equations 1' and 2' reveal the following relationship between optimal labor hiring levels across the two types of firms:

$$\hat{L}_C = (1-H)^{\frac{1}{\alpha-1}} \hat{L}_A \tag{5}$$

As mentioned in the introduction, our primary interest here is in industries in which air conditioning penetration is neither technologically infeasible (e.g. agriculture and construction) nor complete because the costs of adoption are quite low (e.g. office work). Rather, we focus on industries such that some firms within the industry find it profitable to adopt air conditioning and other firms do not. In such a setting, industry-level AC penetration can be determined by solving for a cutoff firm who has a productivity value of θ such that its optimized profits are equal whether it installs air conditioning or not. Setting equation 1 equal to equation 2 (when employment levels are defined by equations 1' and 2') and algebraic manipulation yields the following cutoff θ, which we will denote θ^*:

this model, we are holding the capital stock fixed (so we are solving for short run labor demand). Later in the paper, we discuss how our comparative statics would be affected if both labor and capital can be adjusted once the outdoor heat is known. If capital is less affected by the heat, then this will affect the optimal input mix.

$$\theta^* = \frac{w(\hat{L}_C - \hat{L}_A) + F + E(H)}{p\hat{L}_C{}^{\alpha} - p(1-H)\hat{L}_A{}^{\alpha}} \tag{6}$$

Any firm whose θ is greater than θ^* will adopt air conditioning and any firm below it will not. Note that θ^* will decrease with respect to heat – more firms will adopt AC – if the variable cost of AC increases at a slower rate than the productivity gains from cooling as temperature increases. More formally, differentiating equation 6 with respect to H suggests that AC adoption will increase in temperature if the following condition holds:

$$\frac{\partial\theta^*}{\partial H} = \frac{\left(\frac{\partial E(H)}{\partial H} + w\left(\frac{\partial\hat{L}_C}{\partial H} - \frac{\partial\hat{L}_A}{\partial H}\right)\right)\cdot p[\hat{L}_C{}^{\alpha} - (1-H)\hat{L}_A{}^{\alpha}] - [w(\hat{L}_C - \hat{L}_A) + F + E(H)]\cdot p\left[\alpha\hat{L}_C{}^{\alpha-1}\frac{\partial\hat{L}_C}{\partial H} + \hat{L}_A{}^{\alpha} - (1-H)\alpha\hat{L}_A{}^{\alpha-1}\frac{\partial\hat{L}_A}{\partial H}\right]}{[p\hat{L}_C{}^{\alpha} - p(1-H)\hat{L}_A{}^{\alpha}]^2} < 0 \tag{7}$$

This inequality will hold if and only if the expression in the numerator is negative. Algebraic manipulation and multiplying both sides by H suggests that this condition can be re-expressed as follows:

$$\frac{\left(\frac{\partial E(H)}{\partial H} + w\left(\frac{\partial\hat{L}_C}{\partial H} - \frac{\partial\hat{L}_A}{\partial H}\right)\right)H}{w(\hat{L}_C - \hat{L}_A) + F + E(H)} < \frac{pH\left[\alpha\hat{L}_C{}^{\alpha-1}\frac{\partial\hat{L}_C}{\partial H} + \hat{L}_A{}^{\alpha} - (1-H)\alpha\hat{L}_A{}^{\alpha-1}\frac{\partial\hat{L}_A}{\partial H}\right]}{p\hat{L}_C{}^{\alpha} - p(1-H)\hat{L}_A{}^{\alpha}} \Leftrightarrow \varepsilon_{AC\ costs} < \varepsilon_{AC\ benefits} \tag{8}$$

The probability of AC adoption is increasing in heat if the elasticity of the changes in costs from AC adoption with respect to H is smaller than the elasticity of the gains in revenue from AC adoption with respect to H. This assumption, which we will maintain throughout the modeling exercise, reflects the usual economic argument in the literature that more firms will engage in adaptation strategies under climate change as the returns to adaptation increase. An important distinction in our case is that it is the most productive firms that drive adaptation.

Turning our attention to the macro-level, we can now express aggregate industry-level output as the following:

$$Q = \int_0^{\theta^*} p\cdot\theta(1-H)\hat{L}_A{}^{\alpha}f(\theta)d\theta + \int_{\theta^*}^{1} p\cdot\theta\hat{L}_C{}^{\alpha}f(\theta)d\theta \tag{9}$$

Equation (9) shows that aggregate output is a weighted average of output from firms with and without AC, given their optimal labor choices. Since the most productive firms are the ones that adopt AC and hire more workers per firm, the impact of heat on industry-level output will be smaller than if air conditioning adoption was determined at random.

More formally, we can express the impacts of climate change on industry-level output by differentiating equation 7 with respect to H. This yields the following expression:

$$\frac{dQ}{dH} = \int_0^{\theta^*} \left[\alpha p\theta(1-H)\hat{L}_A{}^{\alpha-1} \cdot \frac{\partial \hat{L}_A}{\partial H} - p\theta \hat{L}_A{}^{\alpha}\right] f(\theta)d\theta + p\theta^* f(\theta^*)\frac{\partial \theta^*}{\partial H} \cdot [(1-H)\hat{L}_A{}^{\alpha} - \hat{L}_C{}^{\alpha}] \qquad (10)$$

The first set of terms captures impacts on the intensive margin. Under climate change, firms without air conditioning will produce less output. The second set of terms captures impacts on the extensive margin. Climate change will induce some additional firms to adopt AC under the assumptions about cost curves outlined above, and the cooled environment will improve productivity within those firms.

Thus, the aggregate impacts of climate change on output can be viewed as the sum of impacts on three types of firms. Low productivity firms in the left tail of the distribution do not adopt air conditioning and suffer under climate change. High productivity firms in the right tail of the distribution are inframarginal since they always had air conditioning and are thus unaffected by climate change.[6] Marginal firms between the two extremes adopt air conditioning as a result of climate change and are thus newly shielded from the impacts of heat. Depending on the degree to which heat is detrimental to labor productivity and the magnitude of climate change, these marginal firms may even experience a boost in productivity relative to their pre-warming levels (although profits will clearly remain lower since they will now incur AC costs that were previously suboptimal to incur).

As in the model of macroeconomic shocks by Gabaix (2011), the 'granular' impacts experienced by large firms exert a non-trivial influence on the aggregate. Only in this case, the effect works in the opposite direction. Since highly productivity firms account for a

[6] Their output will remain unchanged in the heat but their profit will decline as they spend more on operating their air conditioners.

disproportionate share of aggregate output, and those firms are insulated from the impacts of heat, climate shocks will yield rather modest impacts in the aggregate.

II.B. Air Conditioning as an Investment in Worker Productivity and as an Amenity

In this section, we modify our model to capture the fact that a worker's utility is an increasing function of her wage and her comfort on the job. We build on the compensating differentials literature by simultaneously studying the productivity and amenity benefits of AC adoption (Rosen 2002). In particular, we assume that workers prefer a climate-controlled work environment for reasons that are distinct from how that heat affects their productivity. This could arise, for example, if heat exposure during the workday diminishes the marginal utility of leisure after work due to fatigue or because they generally dislike working under hot conditions. If workers face zero mobility costs across jobs and have full information about each job's attributes, they will demand a wage premium for heat exposure on the job (Rosen 2002). Letting X denote this 'extra' pay, we can now express profits for firms without AC as follows:

$$\pi_A = p \cdot \theta(1 - H){L_A}^{\alpha} - w(1 + x(H))L_A \tag{11}$$

Profits for firms with AC remain unchanged from the earlier model. In this setting, the difference in the sizes of labor forces between firm types will be even larger since labor is more productive and less expensive in climate-controlled firms. Combining the first order conditions from equations 2 and equations 9, and algebraic manipulation reveals the following:

$$\tilde{L}_C = [\frac{1 - H}{1 + x(H)}]^{\frac{1}{\alpha - 1}} \tilde{L}_A \tag{12}$$

Optimal labor choices are now denoted by a tilde to distinguish from those chosen optimally when AC was a pure investment good.

As before, the threshold firm skill level theta can be determined by equating optimized profits with and without AC. Let this cutoff level of θ be denoted by $\tilde{\theta}^*$. The value of $\tilde{\theta}^*$ is equal to the following:

$$\tilde{\theta}^* = \frac{w(\tilde{L}_C - \tilde{L}_A) + F + E(H) - w \cdot x(H)\tilde{L}_A}{p\tilde{L}_C{}^{\alpha} - p(1-H)\tilde{L}_A{}^{\alpha}} \tag{13}$$

It is clear by inspection that $\tilde{\theta}^*$ as defined in equation 11 is smaller than the θ^* defined in equation 6. Intuitively, when workers require combat pay to face the heat, more firms find it worthwhile to adopt AC. Moreover, if the elasticity conditions described by equation 8 hold, simple inspection reveals that AC adoption will also be increasing in temperature when AC is a workplace amenity and that it will increase at a faster rate (i.e. $\left|\frac{\partial\tilde{\theta}^*}{\partial H}\right| > \left|\frac{\partial\theta^*}{\partial H}\right|$) for any given level of initial heat H_0.

Industry-level output remains a population weighted average of output for firms with and without AC as can be seen here:

$$Q = \int_0^{\tilde{\theta}^*} p \cdot \theta(1-H)\tilde{L}_A{}^{\alpha} f(\theta)d\theta + \int_{\tilde{\theta}^*}^{1} p \cdot \theta\tilde{L}_C{}^{\alpha} f(\theta)d\theta \tag{14}$$

Two key differences are noteworthy. First, as mentioned above, more firms will install and operate AC so that the set of firms that can be affected by climate change is smaller. Second, firms that continue to operate without AC will hire less labor and produce less output than they did when heat-exposure on the job was not treated as a workplace amenity since labor is now more expensive.

Of particular interest here, is how industry output changes under climate change. Differentiating equation 14 with respect to heat H yields the following expression:

$$\frac{dQ}{dH} = \int_0^{\tilde{\theta}^*} [\alpha p\theta(1-H)\tilde{L}_A{}^{\alpha-1} \cdot \frac{\partial \tilde{L}_A}{\partial H} - p\theta\tilde{L}_A{}^{\alpha}] f(\theta)d\theta + p\tilde{\theta}^* f(\tilde{\theta}^*)\frac{\partial \tilde{\theta}^*}{\partial H} \cdot [(1-H)\tilde{L}_A{}^{\alpha} - \tilde{L}_C{}^{\alpha}] \qquad (15)$$

Recalling that $\tilde{\theta}^*$ is smaller than θ^*, $\tilde{L}_A$ is smaller than $\hat{L}_A$, and $\left|\frac{\partial\tilde{\theta}^*}{\partial H}\right| > \left|\frac{\partial\theta^*}{\partial H}\right|$, it is clear that, for any initial level of heat H_0, the impacts of climate change on aggregate output will be smaller in a world where AC is treated as both an investment and an amenity valued by workers relative to one in which it is a pure investment good.

II.C. A Discussion of Labor Market Extensions

The model developed in Sections II.A and II.B illustrate the importance of heat on the marginal value product of labor and wages in determining optimal AC adoption. In this section, we briefly discuss several extensions to our simple characterization of labor in this setting and their implications for AC adoption and adaptation to climate change.

While our model assumed well-functioning labor markets, real-world labor market imperfections will influence the tradeoff between wages and air conditioning in equilibrium. Two such imperfections seem particularly important in this context. First, the tax treatment between financial compensation and the air conditioning amenity are uneven, with the latter receiving much more favorable tax treatment under the current law. This will clearly skew firms toward more AC adoption when workers treat climate control as a workplace amenity and further insulate firms from the negative impacts of climate change. On the other hand, minimum wage laws, which establish a floor on the financial portion of the wage, will discourage AC adoption for firms where the marginal productivity of labor is most likely to fall below the mandated minimum wage.[7] Since these firms cannot pay workers a lower financial wage as a result of

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[7] Consider the case of Amazon's warehouse in Allentown, Pennsylvania during the summer of 2011. Despite the summer weather, there was no air-conditioning in the depot, and Amazon refused to let fresh air circulate by opening loading doors at either end of the depot—for fear of theft. Inside the plant there was no slackening of the pace, even as temperatures rose to more than 100 degrees. On June 2, 2011, a warehouse employee contacted the US Occupational Safety and Health Administration to report that the heat index had reached 102 degrees in the warehouse and that fifteen workers had collapsed. On July 25, with temperatures in the depot reaching 110 degrees, a security guard reported to OSHA that Amazon was refusing to open garage doors to help air circulate and that he had seen two pregnant women taken to a nursing station. Calls to the local ambulance service became so frequent that for five hot days in June and July, ambulances and paramedics were stationed all day at the

improved work conditions under AC, they are less likely to adopt it. As we have already shown, low productivity firms are already less likely to adopt AC, so the degree to which the minimum wage further discourages adaptation will depend upon how far up the firm skill ladder it binds.

Adding capital to the firm's production function offers the potential of some additional insights. If the productivity of capital is less sensitive to extreme heat than the productivity of labor, then labor-intensive firms will be more likely to adopt air conditioning. In industries where air conditioning is costly and labor and capital are reasonable substitutes for one another, we might also see firms becoming more capital-intensive under climate change. Whether firms shift to capital or adopt AC to insulate their workers from extreme heat, the long run impacts of climate change on output will again be smaller than short-run estimates might suggest.

Lastly, a natural extension to the model we developed earlier is to introduce heterogeneity in the skills of workers. In this case, the most skilled workers will match to most skilled firms since this is where their marginal product is highest, and all of our earlier results will be magnified. High skill firms will account for an even greater proportion of industry output and since they are precisely the firms most incentivized to adopt AC, a greater share of industry input will be insulated from effects from climate change. It is also interesting to note that since AC is a skill biased amenity, it will increases inequality across workers by keeping down the productivity of those with the least skill (and also provide them with more hostile work environments).

III. Data and Empirics

Our empirical results will primarily focus on manufacturing data from the United States. Manufacturing is a particularly interesting setting since the nature of production facilities and what they imply about the costs of AC adoption means that AC penetration is neither zero nor

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depot. Commenting on these developments, Vickie Mortimer, general manager of the warehouse, insisted that "the safety and welfare of our employees is our number-one priority at Amazon, and as general manager I take that responsibility seriously." To this end, "Amazon brought 2,000 cooling bandannas which were given to every employee, and those in the dock/trailer yard received cooling vests."

http://www.salon.com/2014/02/23/worse_than_wal_mart_amazons_sick_brutality_and_secret_history_of_ruthlessly_intimidating_workers/

complete. On more pragmatic grounds, it is also one of the few sectors with a long time-series of rich productivity data. In particular, the NBER Productivity Database provides sectoral annual measures of total factor productivity by 473 6-digit NAICS industry from 1959 to 2009 (see Becker et. al. 2013). These data also report for each industry in each year its real output, labor, capital and energy consumption, and a measure of the share of its workers who are not production workers. Klenow (2005) finds that the share of workers in an industry who are non-production workers proxies for the industry's human capital level.

The NBER data set provides no information on the heat exposure for each industry in each year. To create such heat exposure measures by six digit NAICS industry by year, we combine data from the County Business Patterns (CBP) with state/year data on the count of cooling degree days.[8] The CBP data are available by state/NAICS/year from 1998 to 2012. For each industry, we construct the share of that industry's employment located in each state in each year.[9]

Our climate data source is NOAA. NOAA provides monthly total cooling degree days (on a 65 degree basis) for each month in each year by state from 1895 to the present (see ftp://ftp.ncdc.noaa.gov/pub/data/cirs/climdiv/). We use these data to measure each state's cooling degree days in each year from 1998 to 2009.[10]

Define industry l in state j at time t, we seek to calculate the average cooling degree days that this industry is exposed to in a given year.

$$Cooling\ Degree\ Exposure_{lt} = \sum_{j=1}^{48} Share_{ljt} * Cooling\ Degree\ days_{jt} \tag{16}$$

[8] Cooling degree days (CDD) are a measure of temperature designed to assess energy demands for air condition. CDD equals the number of degrees by which the average temperature in a given day exceeded 65 degrees Fahrenheit. For example, a day with an average temperature of 80 degrees corresponds to 15 CDD and a day with an average temperature of 50 degrees corresponds to 0 CDD.

[9] Due to top coding, we use the categorical variables and use the midpoints of employment in each category. For firms with over 1000 people, we assume they have 1400 people. We have experimented with this assumption. A second issue that arises with the CBP data is that the industries are defined by SIC codes over the years 1986 to 1997 and by NAICS codes from 1998 to 2009.

[10] Cooling degree days (CDD) are a measure of temperature designed to assess energy demands for air condition. CDD equals the number of degrees by which the average temperature in a given day exceeded 65 degrees Fahrenheit. For example, a day with an average temperature of 80 degrees corresponds to 15 CDD and a day with an average temperature of 50 degrees corresponds to 0 CDD.

In this equation, cooling degree days stands for state j's time t count of cooling degree days. As shown in the equation, we weight this using the CBP data on the share of the industry l's jobs in state j in the year t. The share variable sums to one for each industry l in year t and the share is based on employment defined as;

$$Share_{ljt} = \frac{Employment_{ljt}}{Employment_{lt}}$$

This cooling degree exposure represents the count of cooling degree days that the average worker was exposed to in that industry/year. We recognize that within state variation in summer temperature introduces measurement error but given the high degree of within state spatial correlation in climatic conditions this suggest that the measurement error concern is limited to larger states such as Texas and California. In results available on request, we reproduce our core results based on analysis that excludes these large states and our results are qualitatively unchanged.

Table One uses equation (16) to calculate the employment-weighted exposure to cooling degree days by industry over the years 1998 to 2009. Recall that an industry's climate exposure is a function of where it clusters and the count of cooling degree days in that area. Profit maximizing firms will calculate their indirect profit function in each location and choose the location that maximizes their profits (see Carlton 1983, Kahn and Mansur 2013). While industries cluster in specific locations, we will document below they are spread across the United States and this creates some spatial diversification against heat shocks.

We report the weighted mean for the entire year and for the summer months. In the right columns of Table Two, we report the empirical distribution. For example consider the 25th percentile for NAICS 313. It equals 984. This means that 75% of workers in NAICS 313 were exposed to more than 984 cooling degree days on average per year. The right tail at the 90th percentile suggests that all industries experience significant amounts of heat (and thus have latent demand for AC) in the extremes.

Since cooling degree exposure could be high for a given industry because it tends to cluster in hot places (such as the South) or because the location it located in suffered a severe heat wave in that year, it is informative to look at the distribution of industries over space. Table Two takes the County Business Patterns and reports the concentration of employment in the five states with the largest share of the industry. These five states differ depending on the industry; very few industries are highly clustered in a single state. NAICS 315 is the only industry with a greater than 20% concentration in any one state. Table Two highlights that U.S manufacturing is spatially diversified against spatial climate shocks. Manufacturing takes place across many states. While heat shocks are likely to be spatially correlated, this spatial variation offers a source of diversification that merits future research.

In Table Three, we compare the empirical distribution of cooling degree exposure (based on equation 18) for the entire U.S population (in the years 1980, 1990 and 2000 and for the distribution of manufacturing employment in 1998 and 2012). Firms tend to locate in hotter places than the general population, perhaps reflecting limited industrial activity in the upper latitudes within the US. In hotter environments, the exposure of firms and the general population looks rather similar.

III.A. The Empirical Framework

We seek to test whether U.S manufacturing industries' aggregate TFP has been affected by the heat during the time period 1998 to 2009. The unit of analysis is a 6 digit NAICS/year.

$$\mathrm{Y}_{lt} = industry + year\ dummies + B * Cooling\ Degree\ \ Days_{lt} + U_{lt} \qquad (17)$$

In estimating equation (17), we will report results using several different dependent variables and one of them will be the log of a given industry's TFP in a given year. As shown in equation (17), we include 3 digit industry fixed effects and year dummies. For several outcome indicators, we seek to test whether B is negative and statistically significant. Our other dependent variables include, the log(energy consumption per dollar of value added), the log(energy per worker), the log(energy per unit of capital) and the log of the capital to labor ratio. The standard errors are clustered by six digit NAICS.

Table Four presents the main results. We report eight estimates of equation (17). Cooling degree days has a mean of 1,176 and a standard deviation of 284. In column (1), we find that a standard deviation increase in CDD would increase energy consumption per unit of output by 5.9% and would increase energy consumption per worker by 12.5%. Column (5) presents the TFP regression. We fail to reject the hypothesis that heat is unassociated with industry TFP. In column (7) we find that heat is associated with substituting from labor to capital.

We recognize that there could be a non-linear relationship between heat exposure and these outcomes. In columns (2,4,6,8) we report these same regressions where we replace cooling degree days and instead spline it with one knot at the median of the empirical CDD distribution for the industry/year sample (CDD=1,148). The results are interesting and intuitive. Below the median, greater heat reduces energy per unit of output and energy per worker (perhaps because less natural gas is used). Above the median, increases in CDD are associated with greater energy consumption per unit of output and greater energy consumption per worker. As shown in column (6) industry TFP is not negatively affected by heat above the median.

In Table Five, we further explore the nonlinear relationship between heat and industry outcomes by introducing a four knot spline (at the CDD distribution 0-25th, 25th-50th, 50-75th, 75th). Interestingly, energy consumption per worker is most positive for the highest knot, and TFP is not negatively affected by this heat.

These industry-macro results support the hypothesis that U.S manufacturing has made investments to insulate itself from heat damage.

III.C. Testing for Heterogeneous Cross-Industry Effects

In this section, we report augmented estimates of equation (17) in which we interact cooling degree days with industry level attributes. Table Six reports data from one novel data source.[11] We use data from the Manufacturing Consumption Survey for the years 1998, 2002 and 2010 to calculate for 3 digit NAICS industries the percentage of electricity consumed for air conditioning and the quantity of total kilowatts of electricity consumed for air conditioning per worker. The EIA's Manufacturing Energy Consumption Survey was conducted in 1998, 2002, 2006 and 2010.[12] The table highlights that industries such as Petroleum use much more electricity for air conditioning than industries such as plastics.

[11] http://www.eia.gov/consumption/manufacturing/
[12] http://www.eia.gov/consumption/manufacturing/data/2010/

In Table Seven, we report estimates of equation (17) where we include three interaction terms. We allow industries to differ along three dimensions. First, we examine the role of establishment size. Using the 1998, we calculate average employees per plant using the national sample. If air conditioning is a local public good and costs are decreasing in scale, we would expect larger firms to have AC and thus temperature to have less of an effect on firm productivity. Our second industry attribute is the human capital measure (the % of workers who are not production workers). Firms that employ more human capital should be more likely to adopt AC to ensure labor productivity stays close to its frontier. Our third measure is the variable reported in Table Six's 4th column (the 1998 3 digit NAICS electricity consumption on air conditioning per worker).

The results reported in Table Seven indicate that industries with more human capital are not less sensitive to the heat. We do find that industries with larger firms are more likely to adopt air conditioning. One intuitive finding is that industries with a higher baseline air conditioning per worker increase energy consumption per worker when it is hotter outside. Again, we find that industry TFP is not associated with outdoor heat.

IV. Conclusion

In an urbanized economy, our ability to adapt to the challenge of climate change hinges on its impact on worker productivity. An active research agenda seeks to estimate how the demand for residential air conditioning will be affected by climate change (see Auffhammer 2011 and Auffhammer and Aroonruengsawat 2014). The micro economics of firm air conditioning adoption has been a neglected topic. If climate change disrupts work schedules and lowers productivity for workers, then per-capita income will grow at a slower rate and consumers will have less disposable income to purchase products to help them offset challenges posed by hotter temperatures and greater weather variability.

In this paper, we have presented a model of AC adoption by heterogeneous firms hiring homogenous workers.[13] The complementarity embedded in the production function means that

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[13] Future research should introduce heterogeneous workers. Such a model could study what are the implications for both income and quality of life inequality from increased heat caused by climate change. If the lowest skill workers

more productive firms have a higher marginal product of labor. If heat exposure diminishes worker productivity, the most productive firms will be the ones most likely to adopt air conditioning and thus the most sheltered from climate shocks. When workers require combat pay for extreme heat on the job, firms further down the productivity ladder will also adopt air conditioning, and a greater fraction of the economy will be insulated from the impacts of climate change.

The key insight from these models is that the decision to adopt AC is not independent of other fundamental parameters that shape firm-level productivity. Since more productive firms are more likely to adopt AC, aggregate industry-level output is less exposed to climate shocks than any randomly selected firm within the industry. A proper accounting of the impacts of climate change on macroeconomic output requires additional information on the distribution of firm types within and across industries.

Our empirical estimates from the US manufacturing sector are consistent with our model predictions. Hotter temperatures lead to more AC usage and no discernible impact on aggregate TFP. It is worth noting, however, that data limitations preclude our ability to test the more subtle predictions of our models. With suitable micro-level data, one could estimate quantile regressions to test whether the heat-output gradient does indeed vary monotonically as a function of the firm's productivity level.

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work for the low productivity firms and earn low wages and are not air conditioned, then climate change will increase over inequality in well being to increase.

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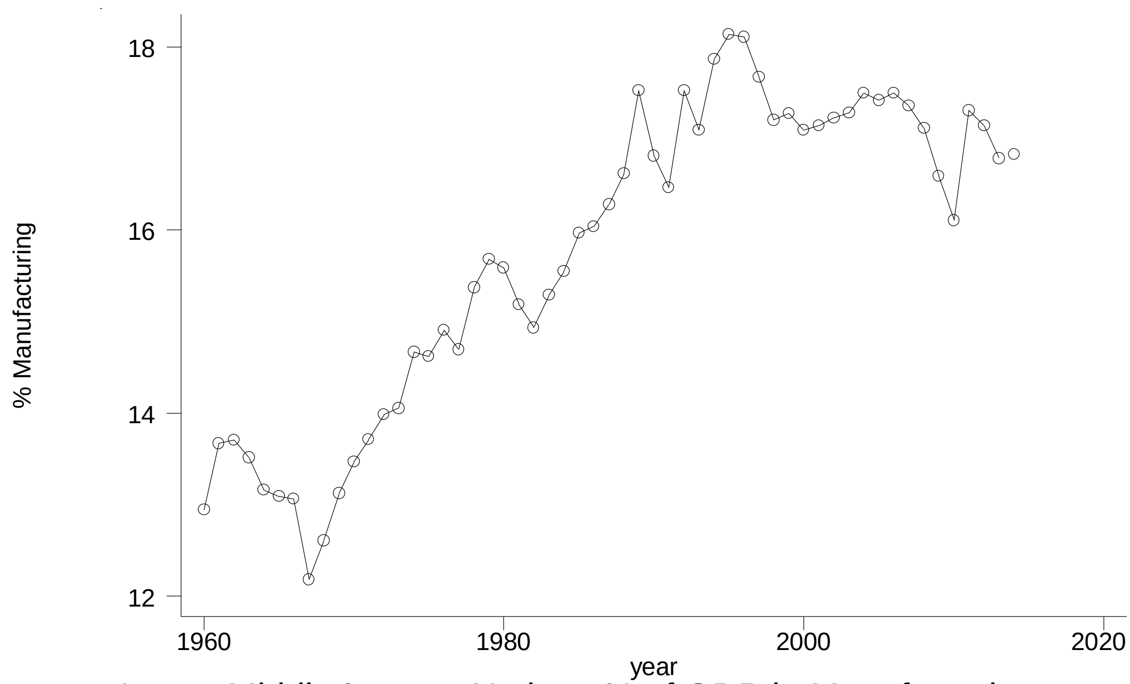
Figure One



Lower Middle Income Nations % of GDP in Manufacturing

Table One

United States Industry Exposure to the Heat

	Industry Exposure to Cooling Degree Days from 1998 to 2009						
			The Empirical Distribution of Cooling Degree Days				
NAICS	Total CDD	Summer CDD	10th	25th	Median	75th	90th
311	1170.665	974.662	428	623	936	1567	2524
312	1235.343	1001.889	415	693	967	1482	2727
313	1409.680	1185.403	589	984	1439	1760	2040
314	1385.049	1132.574	527	780	1367	1760	2243
315	1230.950	1021.406	566	733	967	1569	2243
316	1127.299	923.045	320	560	829	1430	2713
321	1219.345	997.150	261	587	970	1712	2689
322	1137.220	949.765	392	590	877	1554	2227
323	1097.452	915.908	432	594	842	1275	2591
324	1509.526	1189.675	486	739	1057	2664	2834
325	1281.380	1048.816	513	683	967	1704	2724
326	1146.821	963.324	485	653	889	1431	2212
327	1296.974	1048.269	464	668	969	1712	2829
331	1065.121	906.288	464	620	831	1275	2057
332	1149.766	953.617	454	616	857	1405	2689
333	1115.605	934.566	432	599	842	1387	2524
334	1115.736	913.372	373	566	829	1159	2818
335	1157.472	970.960	483	626	936	1482	2158
336	1142.473	952.434	452	636	871	1430	2243
337	1253.076	1033.011	470	684	1014	1616	2591
339	1121.249	922.865	416	589	831	1303	2689

See equation (16) in the text for the details of how the CDD exposure variable is formed.

Table Two

The Geographic Concentration of U.S Manufacturing

	1998 Share of NAICS Employment in the top 5 States										
	Food	Beverage	Textile 1	Textile 2	Apparel	Leather	Wood	Paper	Printing	Petroleum	Chemicals
Ranking	311	312	313	314	315	316	321	322	323	324	325
1	0.107	0.178	0.057	0.098	0.203	0.092	0.069	0.061	0.101	0.114	0.079
2	0.041	0.048	0.129	0.203	0.116	0.087	0.050	0.051	0.071	0.059	0.073
3	0.058	0.078	0.285	0.044	0.100	0.063	0.058	0.053	0.061	0.098	0.056
4	0.052	0.048	0.162	0.103	0.056	0.068	0.059	0.054	0.060	0.067	0.059
5	0.057	0.067	0.048	0.058	0.058	0.066	0.052	0.073	0.053	0.189	0.093
All Other	0.685	0.580	0.318	0.494	0.467	0.624	0.713	0.708	0.653	0.473	0.641
	Plastic	Non-Metalic	Metals	Metals 2	Machinery	Computers	Electric	Transport	Furniture	Other	
	326	327	331	332	333	334	335	336	337	339	
1	0.090	0.087	0.065	0.109	0.074	0.228	0.077	0.079	0.119	0.144	
2	0.066	0.043	0.075	0.074	0.075	0.043	0.082	0.089	0.043	0.049	
3	0.053	0.075	0.060	0.059	0.076	0.063	0.058	0.140	0.048	0.076	
4	0.066	0.065	0.110	0.080	0.079	0.051	0.077	0.089	0.126	0.049	
5	0.093	0.072	0.098	0.066	0.059	0.069	0.055	0.040	0.043	0.054	
All Other	0.631	0.658	0.593	0.613	0.637	0.546	0.651	0.564	0.621	0.628	

Table Three

Population and Manufacturing Exposure to the Heat

Cooling Day Exposure					
	Population			Manufacturing	
	1980	1990	2000	1998	2012
1%	84	230	114	265	165
5%	358	268	298	320	498
10%	461	430	376	516	639
25%	590	517	478	665	769
50%	787	867	831	842	1071
75%	1577	1478	1712	1636	1608
90%	2796	2712	3004	2649	3096
95%	2796	3729	3352	3193	3096
99%	3263	3729	3352	3827	3555

See equation (16) in the text for the details of how the CDD exposure variable is formed.

Table Four

The Direct Effect of Heat on Manufacturing Outcomes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Log(Energy/Output)		log(Energy/Worker)		log(TFP)		log(Capital/Labor)	
CDD in 1000s	0.219**		0.442***		0.016		0.289**	
	(0.111)		(0.153)		(0.025)		(0.121)	
CDD in 1000s (spline below median)		-0.431**		-0.587**		0.081		-0.692***
		(0.195)		(0.235)		(0.057)		(0.213)
CDD in 1000s (spline above median)		0.483***		0.859***		-0.010		0.688***
		(0.142)		(0.206)		(0.029)		(0.142)
Constant	-4.628***	-3.962***	0.387*	1.439***	-0.034	-0.100	3.970***	4.974***
	(0.145)	(0.212)	(0.199)	(0.254)	(0.032)	(0.062)	(0.156)	(0.232)
Observations	5,674	5,674	5,674	5,674	5,674	5,674	5,674	5,674
R-squared	0.489	0.496	0.568	0.580	0.098	0.099	0.446	0.463
Robust standard errors in parentheses								

See equation (16) in the text for the details of how the CDD exposure variable is formed. Year and 3 digit NAICS fixed effects are included in each regression. Standard errors are clustered by industry.

Table Five

Additional Estimates of the Impact of Heat on U.S Manufacturing

	(1)	(2)	(3)	(4)	(5)	(6)
	Log(Energy/Worker)			log(TFP)		
CDD in 1000s (spline below median)		-0.588**			0.076	
		(0.236)			(0.056)	
CDD in 1000s (spline above median)		0.857***			-0.014	
		(0.207)			(0.029)	
CDD in 1000s	0.440***			0.012		
	(0.154)			(0.025)		
CDD in 1000s (Spline up to 25th Percentile)			-1.141***			-0.002
			(0.349)			(0.063)
CDD in 1000s (Spline 25th Percentile to Median)			0.504			0.144
			(0.403)			(0.108)
CDD in 1000s (Spline Median to 75th percentile)			0.303			0.069
			(0.541)			(0.088)
CDD in 1000s (Spline 75th Percentile and up)			0.895***			-0.042
			(0.279)			(0.040)
Constant	0.389*	1.441***	1.907***	-0.028	-0.093	-0.029
	(0.200)	(0.255)	(0.333)	(0.032)	(0.061)	(0.061)
Observations	5,674	5,674	5,674	5,674	5,674	5,674
R-squared	0.569	0.581	0.582	0.126	0.128	0.129
Robust standard errors in parentheses						
*** p<0.01, ** p<0.05, * p<0.1						

See equation (16) in the text for the details of how the CDD exposure variable is formed. Year and 3 digit NAICS fixed effects are included in each regression. Standard errors are clustered by industry.

Table Six

Industry Characteristics

	% of KWH Used for Air Conditioning			MWH Per Worker per Year for Air Conditioning		
NAICS	1998	2002	2010	1998	2002	2010
311	0.083	0.070	0.079	3.465	3.158	4.267
312	0.137	0.114	0.101	5.582	5.439	5.985
313	0.139	.	0.122	10.919	.	14.848
314	0.121	.	0.164	2.720	.	3.570
315	0.253	0.229	0.264	2.048	2.401	2.482
316	0.167	0.113	0.218	1.566	1.769	1.900
321	0.053	0.068	0.062	1.959	2.654	2.714
322	0.051	0.044	0.044	6.272	5.953	7.299
323	0.182	0.180	0.242	3.223	3.692	6.507
324	0.034	0.034	0.037	11.731	12.362	17.352
325	0.059	0.064	0.062	11.096	11.643	11.196
326	0.091	0.092	0.099	4.684	5.017	6.753
327	0.051	0.063	0.059	3.975	5.359	5.267
331	0.031	0.037	0.037	8.202	10.894	12.426
332	0.094	0.101	0.095	2.666	3.026	2.724
333	0.185	0.184	0.202	3.640	3.885	4.283
334	0.260	0.286	0.297	6.208	8.693	9.653
335	0.139	0.171	0.155	3.792	4.790	4.650
336	0.156	0.189	0.187	4.723	5.637	5.854
337	0.138	.	0.178	1.901	.	2.450
339	0.308	0.202	0.254	4.849	2.783	3.183

Table Seven

Testing for Heterogeneous Effects of Heat on U.S Manufacturing Industries

	(1)	(2)	(3)	(4)
Explanatory Variables	log(Energy/Output)	log(Energy/Worker)	log(TFP)	log(Capital/Labor)
CDD in 1000s	-0.736***	-0.791**	0.136*	-0.798**
	(0.226)	(0.327)	(0.076)	(0.311)
CDD in 1000s*1998 MWH on AC per Worker	0.124***	0.224***	-0.005	0.151***
	(0.032)	(0.046)	(0.007)	(0.031)
CDD in 1000s*% High Human Capital	0.927	0.258	-0.096	0.666
	(0.727)	(0.851)	(0.261)	(0.921)
CDD in 1000s*firm size	-0.000	-0.002	-0.001**	-0.001
	(0.001)	(0.002)	(0.000)	(0.001)
Firm Size	0.001	0.006***	0.001***	0.004**
	(0.002)	(0.002)	(0.000)	(0.002)
% High Human Capital	-2.622***	-0.943	0.172	-0.439
	(0.851)	(0.989)	(0.276)	(1.102)
Constant	-3.829***	0.484	-0.173*	4.030***
	(0.312)	(0.387)	(0.092)	(0.399)
Observations	5,674	5,674	5,674	5,674
R-squared	0.538	0.633	0.107	0.524
Robust standard errors in parentheses				
*** p<0.01, ** p<0.05, * p<0.1				

See equation (16) in the text for the details of how the CDD exposure variable is formed. 3 digit NAICS fixed effects, year fixed effects and 3 digit NAICS time trends are included in each regression. Standard errors are clustered by industry.