Price Shocks and Scientific Production: Evidence from Minimum Wages and University Procurement Contracts

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Abstract

This paper identifies the elasticity of demand by academic scientists for both physical materials and trainees as well as the impact of changes in these inputs on the rate and direction of innovative activity. Using rich administrative data from the accounting records of thousands of labs at U.S. research universities, we examine the impact of two types of price changes in an event study and difference-in-differences framework. First, we leverage changes in state minimum wage laws to estimate how labs respond in their use of postdoc, graduate student, undergraduate, and research staff labor. Second, we draw on novel data on university procurement contracts to estimate how labs respond when the price of speciality gases change. We find that scientists employ fewer low wage trainees (undergraduate research assistants) in response to minimum wage changes, and slightly increase their use of graduate students. Labs using more specialty gases prior to the price changes decrease their use of gases when prices increase, but we observe no substitution effects. Our results show that price shocks for specialized inputs matter for scientific production, and there may be a need for insurance mechanisms or increased budget flexibility. Universities seeking to provide undergraduates with research experience should consider providing faculty with alternate funding sources that are in line with minimum wage levels. In order to continue advancing this research, we are currently collecting data on changes in graduate student stipend levels after re-negotiations of graduate student union contracts to estimate the impacts of these price changes on the employment of graduate students.

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1. Introduction

The production of scientific research often requires highly specialized material and labor inputs. For example, research done for the COVID-19 vaccine required horseshoe crab blood (Arnold, 2020)[1], many sub-fields of biology require agar made from red algae (Callaway, 2015), and many areas of physics and chemistry depend on specialty gases, such as helium, for cooling instruments (Kramer, 2019, 2020). Researchers also rely on labor inputs – postdocs, graduate students, and undergraduate research assistants – who posses specific training or are enrolled in specific education programs. Given the dependence on these specialized inputs, changes in the prices of materials and workers' wages might have significant impacts on the demand for these inputs, which can in turn shape the rate and direction of scientific and innovative activity. While there is extensive research on *firm* responses to input price changes, and despite the importance of scientific research for economic growth, there is relatively little research on how scientists in university laboratories respond to price shocks.

In this paper, we estimate the elasticity of demand by academic scientists for both physical materials and lab personnel using rich administrative data from the accounting records of thousands of labs at U.S. research universities (UMETRICS). We leverage two types of input price changes. First, we examine how the employment of trainees, such as postdocs, graduate students, and undergraduate research assistants in labs respond to discrete jumps in wages caused by changes in minimum wage laws. Second, we examine how labs respond when the price of scientific materials change when university procurement contracts are renegotiated or have *force majeure* price adjustments. Finally, by matching scientists to their scientific publications, we examine the impacts of these input price changes on the rate and direction of scientific activity produced by affected scientists.

A third price shock, changes in graduate student stipend levels, will also be

[1]Scientists used the blood cells for the Limulus Amebocyte Lysate (LAL) test to ensure new vaccines are free of bacterial contaminants.

analyzed in the next revision of this manuscript. We are currently collecting data on changes in graduate student stipend levels due to re-negotiations of graduate student union contracts in order to estimate the impacts of these price changes on the employment of graduate students.

Using a difference-in-differences event study design approach, we compare research labs facing price changes due to either state minimum wage law changes or the renegotiation of the university-level gas contracts with labs facing stable prices at the same time. We estimate both event study and two-way fixed effects (TWFE) models. We find that scientists employ fewer low wage trainees (undergraduates) in response to minimum wage changes, particularly those employing more undergraduates previously, and slightly increase their use of graduate students. Labs using more specialty gases prior to the price changes decrease their use of gases when prices increase, but we observe no substitution effects.

Our research is motivated by models of the production of scientific knowledge and how shocks to research resources can impact scientific productivity. There is little empirical research that has been able to get inside the black box of the scientific production function to identify the elasticity of demand by labs for specific input factors. As stated by Stephan (1996) in the seminal paper on the economics of science more than 20 years ago, it is still largely the case that economists studying scientific production tend to focus on the "attributes that the individual contributes directly to the process, ignoring the importance of research resources." Empirical estimates of the elasticity of demand for research resources and the resulting impacts on productivity are important for understanding how university labs behave when faced with price changes and which resources are more or less elastic. While theory would predict that total output of a research lab may decline in response to input price increases due to the income effect, a substitution effect would lead labs to change the composition of inputs that they use such as through the experiments that they run, or type of trainees they employ in the lab.

Prior work on the research organization of labs has tended to focus on more descriptive single university case studies, while we are able to draw on a large sample of labs at different universities and leverage exogenous variation in prices to estimate causal effects. We are able to observe decisions within research labs in order to understand the short-term causal impact of price shocks on labor organization, particularly on trainees.

Some research has shown that scientists' own effort is not responsive to changes in salaries (Goolsbee, 1998), but few studies have been able to identify variation in other input prices and labor inputs used by the scientists. While it is clear from prior work the important role of trainees like students and postdocs in the research production process documented by descriptive case studies, our study fills a gap in empirical evidence on how scientists allocate students in response to wage changes (Carayol and Matt, 2004; Stephan, 1996).

Several important papers have examined the impact of shocks to inputs on scientific production, primarily publications, which are the output of the production process inside of the lab. The detailed accounting data available to us reveals how PIs reorganize labor within the lab and what impact that might have on future trainees and careers.

A related paper to ours is Furman and Teodoridis (2017), who investigate how the rate and direction of science changed following the dramatic reduction in the cost of undertaking vision research following the introduction of the Microsoft Kinect device, as well as Teodoridis (2018) for the impact on labor. In our case, we are estimating the effects generally of price increases rather than a price decrease. Tighter resource constraints might cause different behavior than loosening of budget constraints.

Previous work on the responses of scientists to changes in their resource constraints have estimated the long-term impact of the exogenous destruction of physical capital and human capital to scientific production, while we focus on changes in the relative prices of inputs. Waldinger (2016) examines how the destruction of German research laboratories and the dismissal of Jewish

scientists during the Nazi regime affected the research production of those universities over the subsequent 50 years. Baruffaldi and Gaessler (2018) examine 111 events that led to shocks to physical capital stock on paper production. Unlike the physical destruction of tangible assets, in our case changes to the relative prices of inputs is something that scientists are able to respond and adjust to.

Other related papers have focused on human capital shocks, such as Azoulay, Graff Zivin, and Wang (2010) who examine the human capital shock of the death of a superstar collaborator. Others look at shocks in terms of research funding. Myers (2019) examines changes in research direction following the exogenous increase in available of research funding opportunities, while Tham (2018) investigates the impact of short term and temporary interruptions in funding for scientists.

We also contribute evidence from a new setting to the literature on the impacts of minimum wage laws. Most research in this area focus on low-wage workers who would be most likely to be impacted by the increases, but often tend to look at workers in sectors like fast-food or retail. Ours is the first paper to our knowledge to look at minimum wage impacts on scientific production.

Our findings also have important implications for policymakers. Given the uncertainty of price changes for these specialized inputs, our results point to the need for insurance mechanisms or increased budget flexibility by funders and university administrators. For the minimum wage impacts, universities seeking to provide undergraduates with research experience should consider providing faculty with alternate funding sources that are in line with minimum wage levels.

In the next section we discuss the data we use and provide some background about the price shocks we use in our analysis. In Section 3, we describe the empirical strategy. In Section 4, we present the results, followed by the conclusion.

2. Data and Background

We estimate the response of university scientists to input prices changes by exploiting changes in the cost of labor and scientific materials brought about by changes in minimum wage laws and university procurement contracts. Our analysis draws on the combination of multiple data sources providing micro-data on university lab expenditures, employment, and scientific research outputs.

2.1. Administrative Data from University Research Labs

Our primary data source is the UMETRICS database, a collection of administrative records from contributing universities in the United States (Lane et al., 2015). These records include all transactions charged to sponsored research grants, including payments to vendors as well as the employment of workers. The unit of analysis in this database is a transaction or charge to a sponsored research grant. Transactions that are payments to vendors include the name of the vendor and the total amount of the payment charged from the grant. Transactions that represent the employment of a worker include the occupational title of the worker and the number of days that the worker was paid from the associated grant.

The UMETRICS data covers the time period between 2000 and 2019.[2] In total, the data in the UMETRICS database cover $98.9 billion of university R&D spending across 33 major research universities in the United States.

Our sample includes only sponsored research accounts associated with research grants. Only grants that pay a faculty member who also is listed as a principal investigator on an NIH or NSF grant at some point are included. We exclude grants that fund whole centers or departments by filtering out grants

[2]Each contributing university in the UMETRICS sample joined and began contributing data at a different time. Documentation on the number of universities contributing data in each year can be found in the UMETRICS documentation at https://iris.isr.umich.edu/research-data/2020datarelease/.

that pay more than 12 distinct faculty members[3] or that are NIH grants specifically meant for funding a research center.[4] Finally, the grants in our sample must both employee workers and make purchases of scientific materials at some point during our sample time period.

For our analysis, we aggregate the data into two levels. First, we aggregate the transactions into a grant level panel by quarter. For each grant, we sum all transactions in each quarter. Observations include the following variables: the total spending at vendors, the total spending at suppliers of speciality lab gases, and the number of days of employment for postdocs, graduate students, undergraduates, and research staff. [5]

Second, because we are also interested in if principal investigates (PIs) substitute across their grants, we also construct a PI level panel dataset by aggregating to the PI x quarter level. The raw UMETRICS transactions are associated with grants. We call employees who are paid as faculty members for at least three years in our data, PIs. We aggregate to the PI x quarter level by summing the transactions across all of the grants for which the PI is paid at any point. More details about the data constructions are provided in Appendix A.1.[6]

2.2. Minimum Wages

For each observation in our dataset, we found and attached the effective minimum wage based on the geographic location of the university. The minimum wage data comes from Zipperer and Vaghul (2016). The effective minimum wage is defined as the maximum of the federal minimum wage and the min-

[3]We use this cutoff as it represents the 99th percentile in the number of distinct faculty members paid a grant in our data.

[4]We exclude NIH grants with activity codes such as G12, M01, P01, P20, P2C, P30, P40, P42, P50, P51, P60, PL1, PM1, PN1, PN2, T42, U48, U54, UL1, and ULTR.

[5]We use the number of days of labor, which is in contrast to others who have used the total wage bills as outcomes in order to adjust for differences in quality of workers (Fox and Smeets, 2011; Akerman et al., 2015). In this setting, postdocs, graduate students, and undergraduate workers are likely paid one wage within occupational band.

[6]Our method for aggregating to the PI level is consistent with other papers using UMETRICS data, including Ross, et. al. (2021).

imum wage of the state in which the university is located. If a university is located in a city or county with its own minimum wage, we take the maximum over the federal, state, and city or county level minimum wage.[7]

While the UMETRICS data does not provide salary information for individuals in our dataset, previous studies indicate that student employees at universities frequently earn minimum wage.[8] Indeed, minimum wage increases induce employers to switch to student and teenage employees (Lang and Kahn, 1998). Many staff positions at universities also receive minimum wage compensation. A survey conducted by the College and University Professional Association for Human Resources of a select set of universities found that in 2018 approximately 15% of technical and paraprofessional staff at universities earned minimum wage (Brantley, 2021).

In our analysis, we leverage minimum wage changes, where federal, state, or city legislatures voted such changes into law. These changes are therefore exogenous to productivity or hiring decisions of individual research labs within universities. A change in the minimum wage is defined as any time that the effective minimum wage increases over the previous time period. We also focus in some of our analysis on the larger minimum wage changes, which we define as when the effective minimum wage increases from one period to the next by a magnitude above the 75th percentile of minimum wage changes.

2.3. Specialty Gases

Specialty gases are used in a variety of important areas of experimental science, including biology, chemistry, physics, and medicine. For example, Nuclear Magnetic Resonance (NMR) instruments, which allow researchers to analyze the the molecular structure of a material by observing the interaction of nuclear spins using a powerful magnetic field, require helium to keep the instruments' magnets at their optimum operating temperature of –269 °C. Physi-

[7] For example, the city of Berkeley in California has its own local minimum wage.

[8] FLSA actually allows students to be paid 15% less than minimum wage (Freeman et al., 1981).

cists also often use helium to conduct low-temperature experiments.

Specialty gases are sold as commodities. Suppliers sell these gas at a specified level of purity and by volume or in a specific tank size. Therefore, conditional on ordered specifications, speciality gases are not differentiated with respect to quality.

Because of fluctuations in the global supply and prices of speciality gases, many universities negotiate procurement contracts that fix the price of each gas for a set period of time. These lengthy and detailed contracts enumerate a price for every single type of gas, purity level, and delivery container. These contracts typically are in force for one year to five years and can be renewed and extended.

The price that a researcher at a university faces for a gas can change for two reasons. First, when procurement contracts expire, a university will renegotiate or extend the contract. The prices of gases in the new contract will adjust to the changes in the costs of each gas. Second, most contracts allow for price adjustments if unexpected changes occur in the global supply or price of a gas by a significant magnitude in between contract renewals. These provisions are sometimes referred to as *force majeure* clauses. When global prices or supply change dramatically, the price that scientists face can change with little warning.[9]

For the subset of public universities in the UMETRICS database, we obtained all available procurement contracts between those universities and the major speciality lab gas suppliers. These contracts were requested through Freedom of Information and Sunshine Act requests.[10]

We parsed those contracts and extracted the price faced by each university for each variety of gases, level of purity, and delivery container for during each

[9]One regular reason for changes in the price of a gas like helium is because of natural gas refineries shutting down for maintenance. In interviews, both gas suppliers and procurement officers at universities expressed that they often do not receive a warning before such shutdowns occur.

[10]In one state, procurement contracts are exempted from Freedom of Information Act requests. In addition, some universities were only able to find more recent contracts, but unable to retrieve contracts from previous years.

quarter in which that administrative data for that university was also available in the UMETRICS database.

The transactions data from UMETRICS only shows the total amount spent at vendors, and not the individual products purchased. Therefore, we can measure the total amount of speciality gas purchased by on a grant in a quarter, but not which specific gases were ordered. We, therefore, construct two price indices for gas purchases and lab materials and use them for deriving quantities of materials purchased.

The first is a price index for speciality gases at a university in each quarter. We construct this price index as a weighted average across the prices of the different lab gases enumerated in the procurement contracts. The weights used for each gas are derived from data on the total quantity of each gas purchased at three universities in three years.[11] By dividing the total spending at specialty gas suppliers by the price faced by the university, we construct a variable for the quantity of gas purchased and charged to a grant.

We also attach a price index for all other laboratory materials. This price index comes from the Bureau of Labor Statistics (BLS) Producer Price Index for laboratory and scientific equipment. By dividing the total spending at all vendors other than the specialty gas suppliers by this price index, we construct a variable that represents the quantity of non-gas materials purchased on the grant.

More details on the parsing of the procurement contracts as well as the construction of the price indices and the quantity measures can be found in Appendix A.2.

In our analysis, we leverage the timing of price changes in speciality gases at the university level. For gas prices, the timing of price changes is determined either by a university's gas supplier increasing prices because of a large fluctuation in global prices or because a university's contract expired and was renegotiated. Global prices in gas fluctuated because of idiosyncratic reasons,

[11] We only have this data for three universities in three years.

such as demand shocks, diplomatic fights, and natural disasters. These are unrelated to the operations of individual research labs. Contract terms and re-negotiations occur for entire universities and typically also had little to do with the individual research labs. In addition, some university gas supplier contracts are driven by their need for gases, such as liquid oxygen, for their medical centers rather than primarily for their research labs.

We also use variation in the magnitude of the price changes. For gas prices, changes came about through negotiated contract rates. Interviews with university procurement officers revealed that such officers did not often engage in sophisticated negotiations. Furthermore, procurement officers often felt obliged to accept the prices offered by a supplier since there are few suppliers in many geographic regions creating little competition. In addition, suppliers could and did change the prices when the global price changed markedly.

2.4. Bibliometric and Grant Data

Finally, we collect information on the scientific outputs of the PIs and grants. For each grant, we searched and collected all of the publications in the Web of Science bibliometric database that acknowledge that grant. In addition, we collected all the publications listed in the PubMed database that acknowledged the grant. As a measure of the rate of scientific output, we count the number of distinct publications across WoS and PubMed acknowledging a grant in a year. As a measure of the impact of these publications, we collect the total number of forward citations to those publications during the subsequent five years as well as whether or not those publications would be classified as "disruptive" using the classification of Funk and Owen-Smith (2017). As a measure of the direction of the scientific output, we examine changes in the keywords associated with an article or in the full-text of the article when available through open access.

2.5. Descriptive Statistics

Figures 1a traces the gas price index at universities in the sample over time. Each line on the graph represents the price index of gas at an institution. This plot demonstrates the large amount of variation in the price-level across universities, with some institutions paying almost twice as much as others for precisely the same commodity.

Figure 1c shows the distribution price changes that occur within our sample. Many changes are less than 5%, however, extremely large changes of more than 30% price increases also occur.

In addition to variation in the price level and price changes, there is considerable variation across universities in the timing of price changes and the length of time between price changes. Appendix Figure A.2a shows a tabulation of the quarter in which the price of gas changed. These changes are spread across the quarters of the year. Appendix Figure A.3a shows the distribution of the length of times between price changes within a university. While approximately 30% of price changes occur within a year, many changes occur both within a year while others lasted for four years.

Figure 1b shows the effective minimum wage across universities in the sample, while Figure 1d shows the distribution of the percentage change in minimum wage for changes that occur within our sample. Most changes are small and less than 5%, however, changes of more than 25% do occur.

Appendix Figure A.2b shows when minimum wage changes occur. The majority of these changes occur during the first quarter of the year, however, a bit under 40% of the minimum wage changes occur in other quarters. In Appendix Figure A.3b, the distribution of the length of time between minimum wage changes for universities is displayed. This plot shows that most universities have these changes occurring every year.

We show in Table 1 summary statistics for the attributes of the (lab, grant, quarter) observations. The first column shows the attributes on all observations. The second column shows the observations that have gas price infor-

mation. The third column shows the observations with minimum wage data. The final column shows the attributes for the sample with both gas prices and minimum wage data.

Labs vary in the usage of inputs like gas and workers of different occupational levels. In Appendix Figures A.4a, we show the distribution of the share of vendor spending of a grant that goes to speciality gas suppliers. In Appendix Figures A.4b, we show the distribution of the share of days of work that are undertaken by undergraduate employees.

3. Empirical Strategy

Our empirical strategy uses a difference-in-differences event study design and two-way fixed effects models to estimate the causal effect of input price changes. To identify the effect of input price shocks we exploit three types of variation: variation in the timing of factor price changes, variation in the magnitude of the price changes, and variation in the exposure to price changes based on the intensity of usage of input factors.

Our first approach uses an event study design around the time of gas price and minimum wage changes. For this method, we follow the implementation of (Fuest et al., 2018). The regression equation we use for the event study analysis is as follows:

$$\ln(Y_{f,t}) = \sum_{j=-4}^{5} \gamma_j D^j_{f,t} + \mu_f + \mu_t + \epsilon_{f,t} \tag{1}$$

The dependent variable $Y_{f,t}$ is the outcome of interest of grant f in quarter t. The independent variables include $D^j_{f,t}$, which is a dummy variable that takes the value one when a gas price change or a minimum wage change occurs j periods in the future. We bin the end points, so that all years outside of the event window are included in the endpoints [CHECK THIS]. We also include

fixed effects for the grant, μ_f, as well as the quarter μ_t.

The event study estimates are useful for three reasons. First, they help us trace the dynamic effect of the input price change. Specifically, we can establish if the effects are level shifts in the outcome or dynamic changes. Second, they help us establish that the there are no pre-trends in the outcomes of interest. Third, by examining outcomes or grants that should not be effected by these price changes we effectively have placebo tests.

The identification of the effect of the input price changes in the event study comes from variation within universities over time after controlling for secular time effects. A potential challenge to the causal interpretation could be if universities have contrasting seasonal patterns. For example, universities that are on quarter systems versus a semester system might have different seasonality patterns in spending and employment such that the quarter fixed effects are not able to fully control.

In addition, only labs that utilize speciality gases or undergraduate research assistants would be exposed to the effects of price changes in those inputs. Therefore, we also run a version of the event study that leverages variation in the exposure to the effect of the price change *within universities*. This method parallels those used by (Card, 1992; Derenoncourt et al., 2021), who use geographic variation and firm-level variation in order to define exposure to minimum wage changes.

We compute two measures of exposure to gas price and minimum wage changes. First, we define a lab as being more exposed to the gas price changes if a larger share of the typical spending of the lab is on specialty gases. Thus, we use the share of vendor spending in the quarters prior to the first price change experienced by a PI as their exposure to gas price changes. Second, we define a lab as more exposed to minimum wage changes if a larger share of the work in the lab is performed by undergraduate workers. Here, we use the share of work days charged to the grant for work performed by undergraduate research assistants in the time prior to the first minimum wage change as the exposure

to minimum wage changes.[12]

The following equation estimates the event study model with the intensity measure:

$$\ln(Y_{f,t}) = \sum_{j=-4}^{5} \gamma_j D_{f,t}^{j} \times N_f + \mu_f + \mu_t + \mu_{i,t} + \epsilon_{f,t} \tag{2}$$

In this regression, the covariate N_f represents the exposure measure. It is interacted with the indicator for the price change occurring.

In addition to isolating the effect of the price change for those labs that are likely to be most exposed to the price changes, the approach also allows us to better control for the university specific seasonable patterns. Because the above regression also leverages variation within a university using labs that are differentially exposed to the price change, we are also able to include university specific time fixed effects, $\mu_{i,t}$. This means that we are able to control for secular patterns at a university that may induce all labs to increase or decrease employment and spending during certain quarters of the year.

The previous event study design help us establish that the price changes are leading to changes in input use and that the outcomes are not systematically trending prior to the price changes. We also estimate the following two-way fixed effects (TWFE) model to compute the aggregate elasticities of factor demand:

$$\ln(Y_{f,t}) = \delta_j \ln(p_{i,t}) + \mu_f + \mu_t + \epsilon_{f,t} \tag{3}$$

where $p_{i,t}$ is the price that lab f at university i faced at time t. In addition to estimating the basic two-way fixed effects model above, we also estimate a "fuzzy" difference-in-differences setup in which we interact the price variable, $p_{i,t}$, with the intensity measure $N_{f,t}$ (de Chaisemartin and D'Haultfoeuille,

[12]The distribution of these intensity measures are shown in Appendix Figures A.4

2018). Here, we can also include university specific time fixed effects, $\mu_{i,t}$.

There are a few threats to the causal interpretation of our analysis. First, if gas contracts or minimum wages are adjusted in response to the productivity or organizational changes within university labs, then the results would be biased due to endogeneity. This seems unlikely for a variety of reasons. For gas prices, universities typically make up a small portion of the market for many speciality gases, such as helium (Bare et al., 2016), and thus are not drivers of the global prices in these. Indeed, speciality gases are often by products of other production, such as the extraction of natural gas. Therefore, the price can fluctuate for exogenous reasons, such as natural gas production plants closing for maintenance or political issues in the Middle East.[13]

Finally, university procurement offices negotiate the rates of these price contracts at the university level. In interviews, university procurement officers stated that they do not typically get lab specific pressures when negotiating the prices of speciality gases.[14]

Another issue could the one identified by Meer and West (2016) regarding the dynamic effects of the price changes as well as the related issues identified by Goodman-Bacon (2018) regarding dynamic heterogeneity in the treatment effect. To address both concerns, we will be adding a robustness check in which we exclude previously labs that were previously treated from the control group of later treated labs.

4. Results

[13] Such as the global decrease in helium supply in 2017 due after a Saudi-led blockade of Qatar due to a political dispute over Qatar's "alleged support for terrorism". See e.g. Butler, D., 2017. Qatar blockade hits helium supply. Nature News, 547(7661), p.16.

[14] The purchase of capital equipment related to speciality gases, such as the purchase of a new NMR machine would be specific and negotiated with a particular lab or department in mind.

4.1. Event Study Estimates

We begin by plotting our estimated event study coefficients from Equation 1 for each type of price change. Figure 2a plots the coefficients for specialty gas, where each point represents the estimated log-change in the quantity of gas purchased following a price change at the university-level relative to one quarter prior to the price change. The blue line uses all price changes, while the green line is for price changes greater than or equal to the 75th percentile in magnitude. In the quarters both prior and following the price change, the coefficients are not statistically distinguishable from the zero for all price changes. For the large increases, there is a slight decline, particularly 3 quarters after the price change. These results indicate that price changes in specialty gas do not significantly impact the average laboratory's quantity of gas purchased, although larger price increases appear to lead to small declines in usage.

Figure 2b plots the estimated event study coefficients from Equation 1 for minimum wage changes, with the dependent variable of the log number of days that undergraduate research assistants are employed on a grant. Again, the blue line shows the estimated results when using all minimum wage changes, while the green line displays the results for changes that are greater than or equal to the 75th percentile. In the quarters prior to the minimum wage change, the coefficients are not statistically distinguishable from the zero. In the quarters following the minimum wage change, the usage of undergraduate employees declines. The effect of large minimum wage increases also create more pronounced negative effects on the employment of undergraduates.

When the price of one input increases, labs might reconfigure other factors of scientific production. In Figures 3a and 3b, we show the effect of gas price and minimum wage changes on the use of labor with all different occupational titles. Figure 3a shows that there is no discernible effect of changes in gas prices on the average usage of any type of labor. In contrast, Figure 3b demonstrates that the main effect of minimum wage changes is through the reduction of the employment of undergraduates and research staff. There are no impacts

on the employment of postdocs, while the use of graduate students is slightly higher but not significantly different from zero. The increase in use of graduate students could reflect a substitution effect in which labs employ more graduate student time in order to compensate for the lower use of undergraduates and research staff.

4.2. Heterogeneous Effects

The effect of specialty gas price and minimum wage changes may be different for labs that are heavier users of certain inputs. For example, the salience of gas price changes might be larger for labs in which gas makes up a larger share of the costs of the lab.

Figure 4a displays the estimates of Equation 1 when the sample is split based on the percentage of spending that went to speciality gases in the period prior to the first gas price change. The effect of price changes on labs' gas usage that spend a relatively small share of their spending on the gas is indistinguishable from zero. In contrast, labs that spend a larger share of their typical spending on gas show a more pronounced response.

Figure 4b displays the estimates of Equation 1 when the sample is split based on the percentage of the work done in their lab in the period prior to the minimum wage change performed by undergraduates. Again, the labs that typically have a small share of the work done by undergraduates show little sign of being impacted by the minimum wage changes, while labs that rely on undergraduate workers show larger effects from the minimum wage change.

The effect of gas price and minimum wage changes may also be different for principal investigators at different stages of their careers. For example, younger researchers may have less ability to quickly raise or substitute other funds to fill a gap due to factor price increases.

Figures 5a and 5b show the estimates from Equation 1 when limited to PIs who experienced the price or minimum wage change during their first two years at an institution versus those that faced that change when they had been a uni-

versity for more than five years. The plots show that PIs with less experience at a university, who are more likely to be experiencing such an input price change for the first time, are impacted more by the gas price changes. Minimum wage changes appear to initially impact the less experienced PIs, but then the more experienced PIs are impacted after 2 quarters, suggesting that it is the junior PIs who are able to adjust in the longer run.

4.3. Two-Way Fixed Effect (TWFE) Estimates

The event study estimates presented so far have demonstrated that the effects of gas price and minimum wage changes on quantity of inputs used are primarily limited to the labs that utilize a higher share of specialty gas and undergraduate labor.

We next estimate the effect of the price and minimum wage changes using a traditional two-way fixed effects (TWFE) specification. Here, we leverage the variation in the intensity of usage of the relevant inputs in the same manner as Card (1992) and Derenoncourt et al. (2021).

In Table 2, we show the estimated coefficients on the price of gas interacted with the intensity of gas usage as well as the minimum wage interacted with the intensity of undergraduate labor usage. The first column shows the coefficient when regressing the usage of gas on the price interacted with the intensity while including quarter and lab fixed effects. The second column includes institution x quarter fixed effects. The estimated coefficients in both of these specifications are negative, however, they are not statistically significant.

The third and fourth columns replicate this exercise with a dependent variable of the usage of undergraduate employee time and the minimum wage interacted with intensity of undergraduate use in the lab. These estimated coefficients are both negative and statistically significant at the 5% level. While the magnitudes are large, they represent the elasticity for a lab that entirely depended on the usage of undergraduates (100% undergraduate labor). In reality, however, the average lab has fewer than 5% of the employee days undertaken

by undergraduates.

The TWFE regressions demonstrate that the elasticity of demand for gas and undergraduate time increases with the intensity of usage of those inputs. However, the interaction term for usage intensity in the TWFE models may not capture non-linearity in the effect of price changes for labs that rely more or less on particular inputs.

In order to explore the potential heterogeneity in the cumulative effect of the price changes, we estimate separate TWFE models for labs based on their intensity of usage of inputs and present the results similar to Cengiz et al. (2019). Specifically, we separate labs into quartiles by use of undergraduates and gas prior to the relevant price changes.[15] We then regress the outcome of interest on the contemporaneous price or minimum wage as well as four quarter leads and two quarter lags, lab fixed effects, and quarter fixed effects. We then take the average effect over the post period and display these estimates for each quartile bin. In addition, we display in purple the effect across all labs.

Figure 6a shows the results for labs by quartile of gas usage. These estimates demonstrate that the negative impact of gas price increases with the usage of gas within labs is found for all three of the highest usage quartiles. Indeed, the greater the usage of gas prior to the price change, the greater the negative response to price increases.

Figure 6b shows the results for labs by quartile of undergraduate labor usage. These estimates indicate that the effect of the minimum wage change is only significantly found for the labs in the highest quartile of undergrad labor usage, namely having more than 15% of their employee-days being done by undergraduates.

[15]For labs that do not use gas or undergraduate workers, we assign them to the lowest quartile. The top three quartiles are evenly sized.

4.4. Outcomes

The previous sections establish that changes in input factor prices can have significant effects on the usage of those inputs. In this section, we explore what impact those price change ultimately have on the production of scientific outputs.

We estimate the following production function of scientific outputs:

$$\ln(Y_{f,t}) = \sum_{o \in \mathcal{O}} \beta^o ln(L^o_{f,t}) + \beta^m ln(Q^{Mat}_{f,t}) + \beta^g ln(Q^{Gas}_{f,t}) + \mu_f + \mu_t + \epsilon_{f,t} \quad (4)$$

where $Y_{f,t}$ represents the number of publications produced by a PI's lab within a year, L^o_{ft} is the number of days of employment of workers with occupation o, $Q^{Mat}_{f,t}$ is the quantity of non-gas materials used by the lab, and $Q^{Gas}_{f,t}$ is the quantity of gas used. The terms μ_f and μ_t represent lab and time fixed effects.

Estimating the above equation using only observable data could be subject to endogeneity concerns. For example, a PI who is especially productive for unobserved reasons, might also tend to employ additional students, staff, or materials, leading to upward biased estimates of the importance of these inputs for productivity. In order to placate such concerns, we instrument for all factors of production. For each factor, we instrument with the one year lag of that input value. In addition, we include both the contemporaneous price of gas and the minimum wage as cost shifters for the gas and labor usage respectively.

The results of the reduced form and IV regressions are shown in Table 3. In the IV specification, only the coefficients on faculty time and graduate student time are significantly associated with publication outputs as well as forward citations. Only faculty time is significantly correlated with the papers being "disruptive."

Much more will be done in future revisions of this paper in order to understand the effect of price changes on the rate and direction of scientific outputs.

4.5. Robustness: Fungibility of Funding and Lab-Level Analysis

When input prices increase, PIs may be able to move money from one pile to another to offset. One might therefore wonder if the results above also hold at the lab level. In this section, we replicate the event study plots at the lab level and demonstrate that PIs are not entirely able to move money around to offset.

We also examine the probability of getting a new grant or expanded funding. If PIs can simply obtain new sources of funding when price changes occur, they may be able to offset any constraint from the input price increases. Figure 7a and 7b show the results of estimating the effect on the number on grants that pay a PI. We see that while not significant for gas price changes, following minimum wage changes PIs draw upon a larger number of distinct grants. More work will need to be done to understand this result.

5. Conclusion & Next Steps

In this paper we have estimated the elasticity of demand by academic scientists for both physical materials and lab personnel using rich administrative data from thousands of research labs facing price changes due to either state minimum wage law changes or the renegotiation of university-level gas contracts.

We find that scientists employ fewer undergraduates in response to minimum wage changes, particularly those employing more undergraduates previously, and slightly increase their use of graduate students. Labs using more specialty gases prior to the price changes decrease their use of gases when prices increase, but we observe no substitution effects.

Given the uncertainty of price changes for these specialized inputs, our results point to the need for insurance mechanisms or increased budget flexibility by funders and university administrators. For the minimum wage impacts, universities seeking to provide undergraduates with research experience should consider providing faculty with alternate funding sources that are in line with minimum wage levels.

Our next steps involve (1) further probing the impacts of these price changes on publications and (2) completing data collection on changes in graduate student stipend levels after re-negotiations of graduate student union contracts to estimate impacts on the employment of graduate students.

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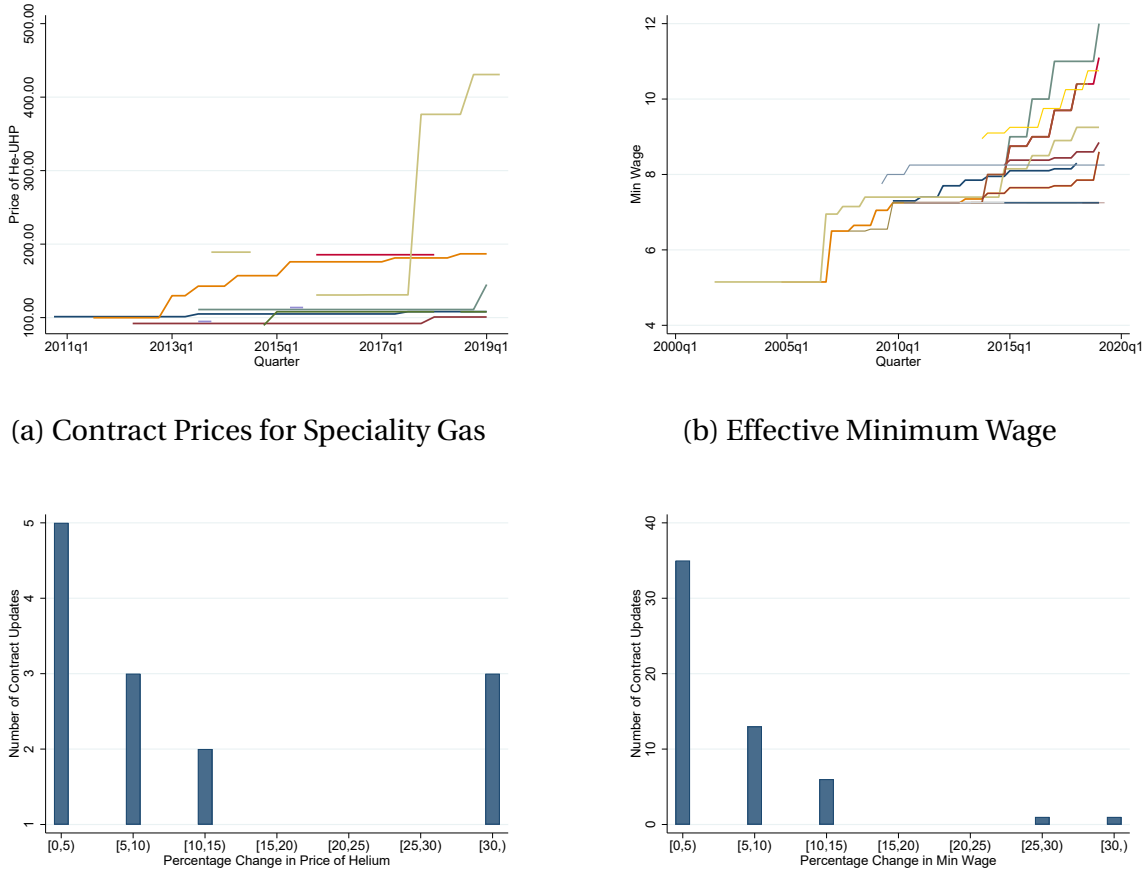
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6. Tables and Figures

Figure 1: Factor Prices at Universities



(a) Contract Prices for Speciality Gas

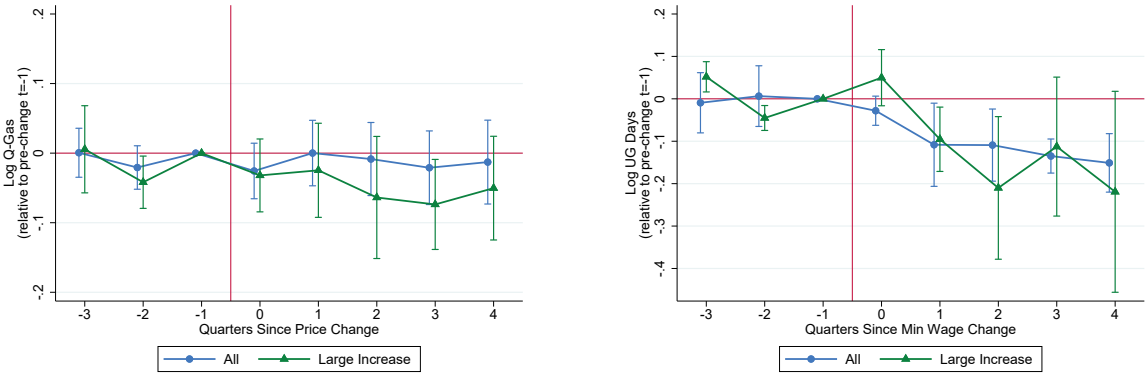
(b) Effective Minimum Wage

(c) Histogram of Price Changes

(d) Histogram of Min Wage Changes

Note: The figure in the top-left shows the price index of speciality gas each quarter at the universities in our sample. Each line in the graph represents one of the universities in the sample. The figure on the top-right shows the effective minimum wage for each university. The figure on the bottom-left shows a histogram of the magnitudes of the price changes between contracts at the same university. The vertical axis displays the number of contracts with a price change of that magnitude in our sample. The bottom-right shows the magnitude of the minimum wage changes.

Figure 2: Effect of Gas Price and Minimum Wage Changes on Gas Purchased and Undergraduate Employment by size of Price Change

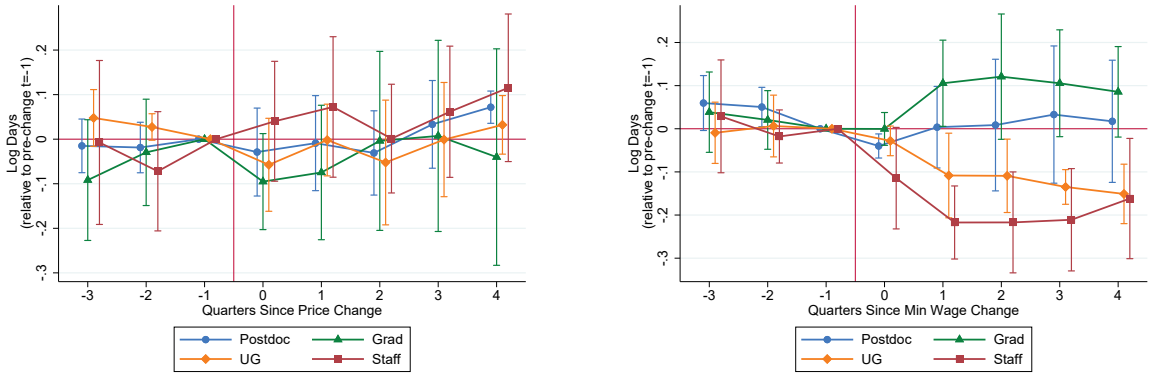


(a) Gas

(b) Undergraduates

Note: The above figures plot event study estimates and confident intervals from Equation 1. On the left graph, the dependent variable is the log quantity of gas purchased plus one. On the right graph, the dependent variable is the log number of days of work performed by undergraduates plus one. The regression model includes grant and quarter fixed effects. Standard errors are clustered at the university level. The blue lines are the estimates using all input price changes, while the green lines represent only price changes that are larger than the 75th percentile of changes in magnitude.

Figure 3: Effect of Gas Price and Minimum Wage Changes on Labor and Materials

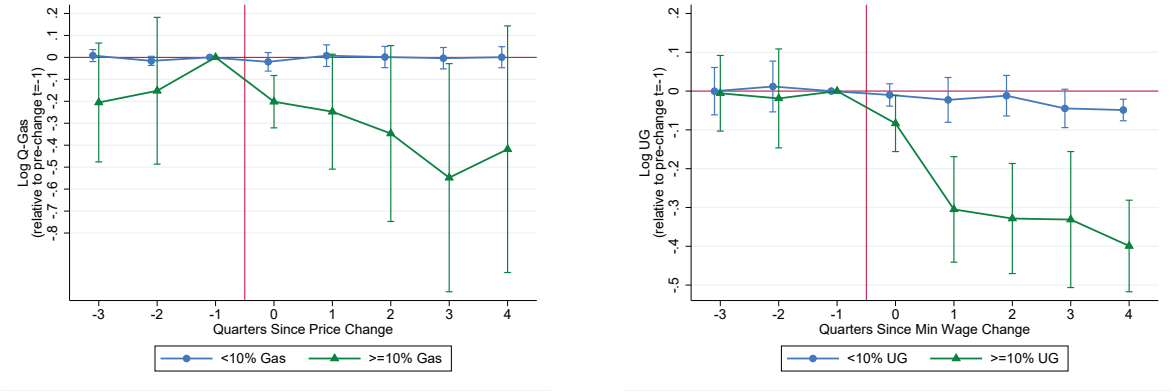


(a) Gas Price Change

(b) Minimum Wage Change

Note: The above figures plot event study estimates and confident intervals from Equation 1. Each line in the graphs represents the estimates from a regression with a different outcome variable. The outcome variables are the log number of days of work performed by employees of each occupation. The regression model includes grant and quarter fixed effects. Standard errors are clustered at the university level.

Figure 4: Effect of Gas Price and Minimum Wage Changes on Heavy Users

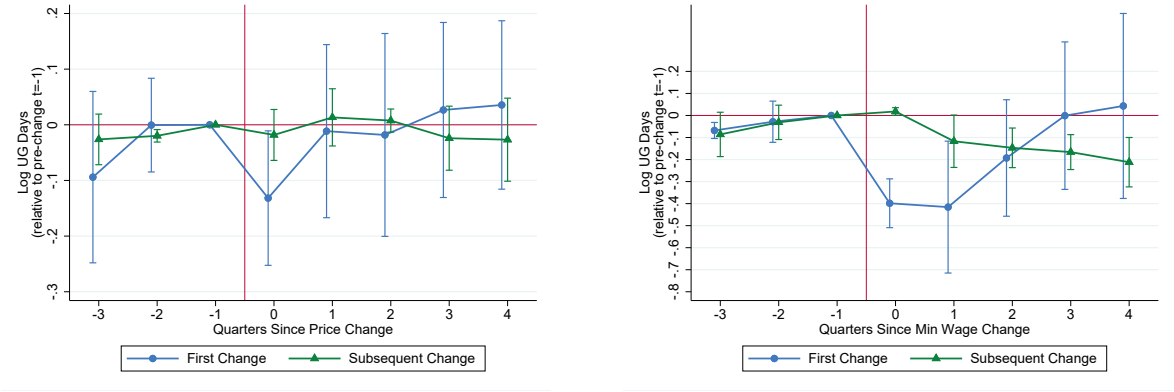


(a) Gas

(b) Undergraduates

Note: The above figures plot event study estimates and confident intervals from Equation 1. On the left graph, the dependent variable is the log quantity of gas purchased plus one. On the right graph, the dependent variable is the log number of days of work performed by undergraduates plus one. The regression model includes grant and quarter fixed effects. Standard errors are clustered at the university level. On the left, the blue line represents labs that had less than 10% of their spending prior to the first price change be on gas, while the green line shows those with more than 10%. On the right, the blue line represents labs that had less than 10% of the days of work performed by employees in the lab be from undergraduates, while the green line shows those with more than 10%.

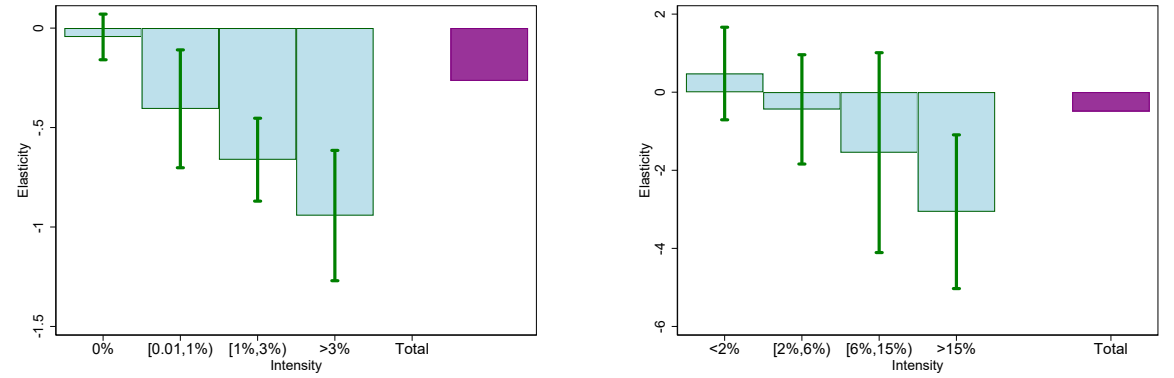
Figure 5: Effect of Experiencing the First Gas Price and Minimum Wage Change



(a) Gas (b) Undergraduates

Note: The above figures plot event study estimates and confident intervals from Equation 1. On the left graph, the dependent variable is the log quantity of gas purchased plus one. On the right graph, the dependent variable is the log number of days of work performed by undergraduates plus one. The regression model includes grant and quarter fixed effects. Standard errors are clustered at the university level. The blue lines are the estimates using only labs that are experiencing their first input price change in our sample, while the green line shows all subsequent changes pooled together.

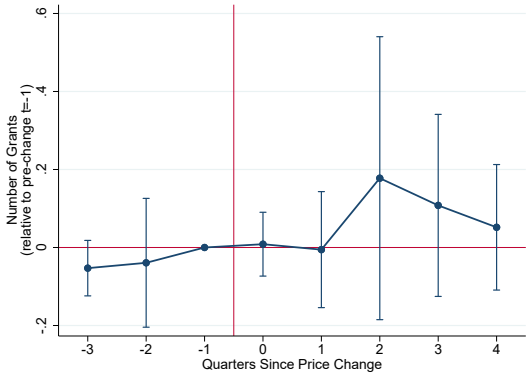
Figure 6: Effect of Price Changes by Usage Intensity using Two-Way Fixed Effects Model



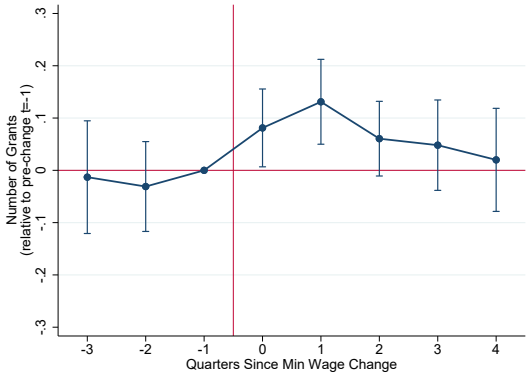
(a) Gas (b) Undergraduates

Note: The above figures plot the sum of the coefficients for the post-price and -minimum wage change effects from the Equation 3 model. We take the average effect in the post-change period and plot that for labs within each quartile of intensity. The lowest intensity bin also includes all labs that do not use gas or undergraduate research assistants respectively. The purple bar represents the total average effect when pooling all labs together.

Figure 7: Effect of Price Changes on Grant Funding



(a) Gas Price Change



(b) Minimum Wage Change

Note: The above figures plot event study estimates and confident intervals from Equation 1. The dependent variable in both figures is the number of grants that a PI charges. The regression model includes grant and quarter fixed effects. Standard errors are clustered at the university level.

Table 1: Summary Statistics

	Grant Level			
	All	Gas Sample	UG Sample	Gas and UG
Direct Expend	55721.1	51964.7	56072.9	53357.9
	(128040.7)	(124461.8)	(131765.1)	(132905.2)
Subaward	6971.5	4778.0	6605.2	4181.7
	(70885.1)	(46482.5)	(72296.5)	(45073.4)
Labor Pay	40342.4	39621.6	41116.2	41924.1
	(95534.6)	(103339.5)	(99287.9)	(111107.9)
Vendor Pay	8272.5	7565.1	8351.7	7252.2
	(57722.3)	(55695.9)	(60654.0)	(60311.1)
Gas Spending	88.12	78.64	79.68	71.92
	(905.5)	(501.8)	(617.3)	(484.0)
NMR Spending	35.32	12.06	34.23	9.543
	(3175.6)	(539.7)	(3236.9)	(462.6)
Price Gas	129.5	129.5	126.0	126.0
	(44.52)	(44.52)	(29.27)	(29.27)
Days Trainee	93.00	64.49	93.00	64.49
	(184.1)	(146.8)	(184.1)	(146.8)
Days Postdoc	27.98	24.24	25.69	17.06
	(81.73)	(95.19)	(67.12)	(46.84)
Days Grad	51.02	44.38	44.31	30.67
	(127.8)	(126.5)	(107.3)	(81.86)
Days UG	22.82	16.81	22.82	16.81
	(91.29)	(92.68)	(91.29)	(92.68)
Days Res. Staff	151.5	115.8	154.0	109.8
	(374.1)	(314.0)	(381.3)	(301.1)
Funded by NIH	0.575	0.496	0.585	0.500
	(0.494)	(0.500)	(0.493)	(0.500)
Funded by NSF	0.143	0.136	0.133	0.118
	(0.350)	(0.343)	(0.340)	(0.322)
Funded by DOE	0.0218	0.0150	0.0214	0.0156
	(0.146)	(0.121)	(0.145)	(0.124)
N	761,436	207,033	647,108	169,844

Note: The above table shows summary statistics for the observations in our data. The main observations are (lab, grant, quarter) observations. The mean value of the variables are shown, while standard error are shown in the parentheses.

Table 2: Difference-in-Differences Estimates

	ln(Q-Gas)		ln(Emps-UG)	
	(1)	(2)	(3)	(4)
Ln(Price Gas) × Share Gas	-2.177	-2.047		
	(-1.59)	(-1.52)		
Ln(Min Wage) × Share UG			-13.88**	-13.05**
			(-2.71)	(-2.54)
N	205,641	205,641	645,450	645,450
N Labs	23,299	23,299	62,031	62,031
Lab FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes
Inst x Quarter FE	No	Yes	No	Yes
R2	0.53	0.53	0.56	0.56
Dep. Mean	0.17	0.17	0.70	0.70

Standard errors clustered at institution level.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: The above table shows the results of estimating Equation 2. An observation is a PI x grant x quarter. The share of gas and undergraduate labor used prior to the first gas price change and minimum wage change respectively are interacted with the contemporaneous price and minimum wage. Fixed effects for the PI and quarter are included. In columns (2) and (4), we also include institution x quarter fixed effects.

Table 3: Production Function of Sicentific Publications

	ln(Publications)		ln(Cites)		ln(Disruptive)	
	(1)	(2)	(3)	(4)	(5)	(6)
$\ln(L^{\text{faculty}})$	0.00557**	0.0461**	0.00142	0.150***	0.000794	0.0229**
	(2.08)	(2.07)	(0.28)	(3.39)	(0.59)	(2.08)
$\ln(L^{\text{postdoc}})$	0.00641***	0.00760	0.0102***	0.0164	0.00120	-0.00538
	(3.38)	(0.96)	(2.79)	(1.04)	(1.25)	(-1.37)
$\ln(L^{\text{grad}})$	0.00487**	0.0356***	0.00753**	0.0657***	0.000748	0.00168
	(2.45)	(3.06)	(1.97)	(2.85)	(0.75)	(0.29)
$\ln(L^{\text{undergrad}})$	0.00988***	0.00212	0.00457	-0.0183	0.00189*	-0.00510
	(4.68)	(0.25)	(1.12)	(-1.10)	(1.77)	(-1.24)
$\ln(L^{\text{staff}})$	-0.00414*	0.0106	-0.00536	0.00986	0.0000615	-0.00207
	(-1.89)	(0.68)	(-1.26)	(0.32)	(0.06)	(-0.27)
$\ln(Q^{\text{Mat}})$	0.00534*	-0.00299	0.00377	-0.0627	0.00192	0.00327
	(1.92)	(-0.10)	(0.70)	(-1.01)	(1.36)	(0.21)
$\ln(Q^{\text{Gas}})$	0.0218***	-0.0404	0.0203**	-0.150	0.00401*	-0.00852
	(4.60)	(-0.85)	(2.23)	(-1.59)	(1.67)	(-0.36)
N	19,183	19,182	19,183	19,182	19,183	19,182
N Labs	3,689	3,689	3,689	3,689	3,689	3,689
Lab FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Instruments	OLS	IV	OLS	IV	OLS	IV
R2	0.56	-0.06	0.50	-0.13	0.37	-0.02
Dep. Mean	0.31	0.31	0.42	0.42	0.06	0.06

Standard errors clustered at the lab level.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: The above table shows the results of estimating Equation 4 at the PI x year level. In the IV specifications, both lags of all input factors, the contemporaneous price of gas, and the contemporaneous minimum wage are used as instruments.

A. Appendix

A.1. UMETRICS Data Construction

The raw UMETRICS data contains transaction data. An observation in this data is a charge to a sponsored research grant. These charges might include purchases at the vendors for scientific materials or equipment. These charges could also be paying for the employment of individuals. Each charge states which grant paid for the transaction, and the total amount of the charge. If the charge represents a purchase, the name of the paid vendor is listed. If the transaction represents the employment of an individual, a unique identifier for the employed worker is listed, the period of time during which the worker was paid, and the occupational title of the individual.

We aggregate these transactions into two

Lab identifiers are not present in our dataset. Instead, we identify unique labs based on inferences from the organizational chart implied by the transactions. First, we find all of the individuals who are employed faculty during every time period in our employment data and who at some point are listed as principal investigators on either an NSF or NIH grant. We call these individuals Principal Investigators (PI). Second, for each of these PIs, we find all of the grants that ever paid that PI. We exclude center grants and grants with more than 11 other faculty members paid from that grant. We also use only grants that have complete accounting data, including employment records, purchases at vendors, and information about the accounting of the grant itself. The combination of the PI and his or her associated grants we refer to as defining their "research group." An observation in our main dataset is a PI x an associated grant of their research group x quarter.

A.2. Price and Quantity Data Series Construction

The dataset used for analysis contains three price series: the minimum wage by institution, a price index of speciality gases by institution, and a price index of scientific materials and

First, we attached the minimum wage faced by each research group in each quarter to the observations in our dataset. For each lab, we find the geographic location of the university that houses that lab. Based on that location, we attach the minimum wage according to data collected by Zipperer and Vaghul (2016). When a sub-state minimum wage based on the sub-state location of a university is available then we collect that wage as well. The effective minimum wage for a lab at a university in a quarter is the maximum of the sub-state, state, and federal minimum wage for that quarter.

Second, we construct a price index for speciality gases at at an institution. This price index tracks the price across many different speciality lab gases. While we have price data for each of dozens of the individual speciality gases, we only observe the total spending of grants at speciality gas suppliers rather than the individual products and gases that they purchased in each transaction. Therefore, we create a composite price index.

Each price agreement with a university typically sets a price for an enormous number of different speciality gases, in all different sized containers, and for a set period of time. For example, the contract would stipulate that Helium at Ultra-High Purity in a T-sized tank of 291 cubic feet would be priced at $138.20 for a period of five years.

Some price agreements also list the quantities of each gas in each container ordered in the previous year. We utilize that information to derive weights for each gas and container to use in constructing the price index.

Quantity of gas spending is defined as the sum total of spending at speciality gas suppliers in a quarter divided by the price index of speciality gas. We construct these quantities at the grant x quarter level.

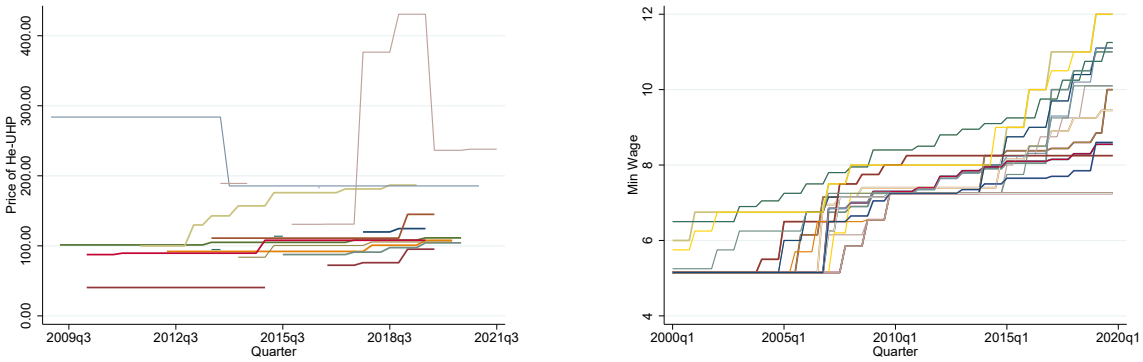
Third, we collect the price index of laboratory equipment from the Bureau

of Labor Statistics' Producer Price Index.

Quantities of non-gas materials are defined by the total spending that does not occur at specialty gas suppliers divided by the producer price index for laboratory equipment.

In the main text, we use data for universities with complete accounting data in UMETRICS as well as complete pricing data for gas or the minimum wage.

Figure A.1: Factor Prices at Universities – Long Panel



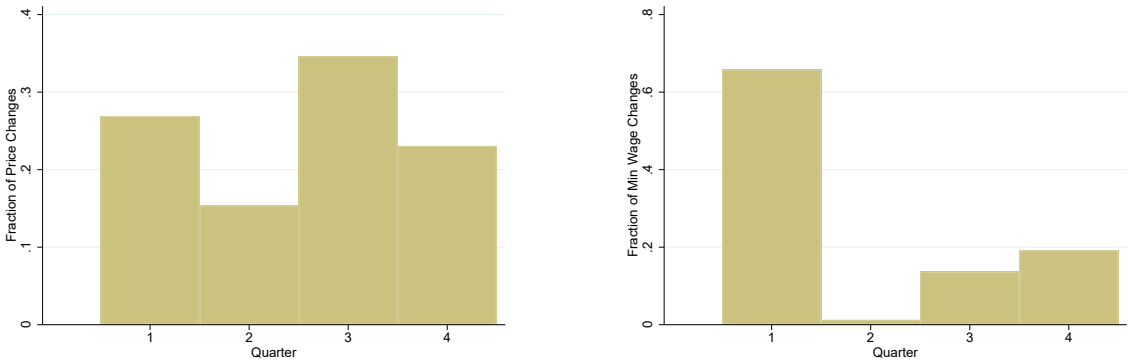
(a) Contract Prices for Speciality Gas

(b) Effective Minimum Wage

Note: The figure in the left shows the price index of speciality gas each quarter at the universities in our sample. Each line in the graph represents one of the universities in the sample. The figure on the right shows the effective minimum wage for each university.

Price changes and minimum wage changes occur throughout the year. In the figures below, we plot the frequency that price changes and minimum wage changes occur in each quarter of the year. The plot shows that price changes in gas prices—either triggered by contract expiration and renewals or by unexpected price changes in the global price of these gases—are spread fairly evenly across the quarters of the year. In contract, minimum wage changes occur predominantly within the first quarter of the year, although some also occur during the summer or late in the year.

Figure A.2: Timing of Gas Price Changes and Minimum Wage Changes

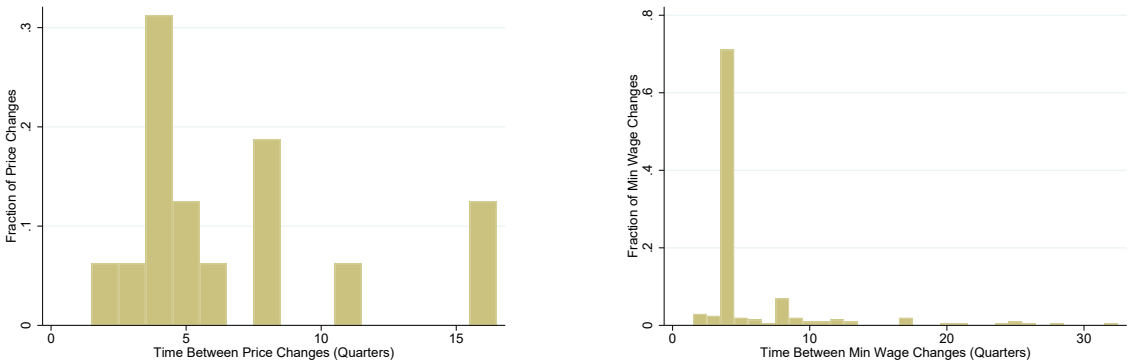


(a) Gas Price Changes (b) Minimum Wage Changes

Note: The figures above show the timing of changes in gas prices and the effective minimum wage at the university level.

The length of time between gas price changes varies. In the plots below, we show the time between gas price changes at a university as well as the time between minimum wage changes. While minimum wage changes occur primarily at one year intervals, gas price changes occur with more variation as an outcome of when global prices change as well as the variation in the length of the contracts in place at universities.

Figure A.3: Length of Time Between Gas Price and Minimum Wage Changes



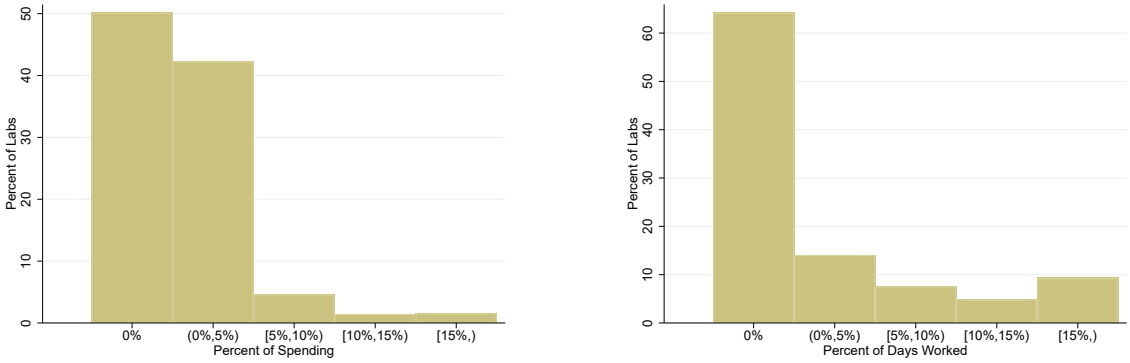
(a) Gas Price Changes (b) Minimum Wage Changes

Note: The figures above show the length of time between changes in gas prices and the effective minimum wage at the university level.

A.3. Distribution of Intensity

We define measures of the intensity of usage of both undergraduate labor and specialty gases for university research labs. For gas usage, we take the total spending on gas prior to the first gas price change experienced by that lab and divide by the total vendor spending of the lab during the same time period. We call this the intensity of gas usage. For undergraduate usage, we take the total number of days of work performed by undergraduates before the first minimum wage change experienced by the lab and divide by the total number of days of work done in a lab during the same time period. We call this the intensity of undergraduate labor usage.

Figure A.4: Distribution of Intensity Measures



(a) Gas Usage

(b) Undergraduate Usage

Note: The figures above show the distribution of intensity measures for gas usage and undergraduate time.