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Limited supply and lagging enrollment: Production technologies and enrollment changes at community colleges during the pandemic ☆

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ABSTRACT

Weak labor markets typically lead young workers to invest in skills. High unemployment during COVID diverged from prior downturns: enrollment at community colleges dropped by 9.5 percent between 2019 and 2020, with the drop larger among men. COVID disruptions generated supply-side impacts on courses of study requiring significant capital and "hands on" experiential learning, particularly programs that deliver assembly, repair and maintenance (ARM) skills. Community colleges that had relative concentrations of credentials in ARM fields pre-pandemic experienced relatively large enrollment declines. The decline in ARM enrollment explains about one quarter of the overall community college enrollment decline, and nearly all the difference in enrollment declines by gender during COVID.

1. Introduction

Weak labor markets and high unemployment typically lead young workers to invest in skill development by lowering the opportunity cost of a degree. In past recessions, post-secondary institutions—particularly community colleges—have seen large increases in enrollment in response to labor market downturns (Betts and McFarland, 1995; Barr and Turner, 2013). But the period of high unemployment tied to COVID diverged markedly from past downturns. Total post-secondary enrollment declined, down 2.5 percent from fall 2019 to fall 2020 during COVID, compared with a decline of 1.3 percent in the prior year when the economy was strong. Enrollment declines at community colleges were yet larger: dropping by 10.1 percent overall between the fall of 2019 and the fall of 2020 (see Fig. 1), and nearly 15 percent among men. In this paper, we explore how supply disruptions produced a decline in community college enrollment during the COVID period, even as unemployment rates were quite high.

COVID introduced unique "shocks" to the delivery of post-secondary education. Depending on local and state mandates, colleges may have had to abruptly shift to online-only formats or may have been able to continue to hold in-person classes but with increased costs due to social distancing requirements (reducing maximum class size conditional on space) and deep cleaning mandates. These shifts not only differ across states, but also have markedly heterogeneous impacts across courses of study.

How COVID-related disruptions impacted community college enrollment is particularly important given the potential role of these institutions in furthering economic mobility. Community colleges serve a large number of students; about one-third of the 16.5 million undergraduate students enrolled in 2019 attend a community college. And, relative to students attending four-year public institutions, community college students are more likely to be age 25 or older (31.5% versus 18%).[1] Many students enroll in short-duration certificate programs in fields such as health, business, repair, security and production, which may position them for new employment opportunities. Over 40 percent of community college awards are certificates, the majority of which require less than one year of study. Long-standing evidence indicates positive returns on average to community college attainment (Kane and Rouse, 1995), with the returns to career and technical education coursework for adult learners shown to be particularly strong (Jacobson et al., 2005; Cellini and Turner, 2019). Yet, when enrollment demand for community colleges has increased during prior downturns, it appears that more students take remedial and general academic subjects—which generally do not have sizeable labor market returns. The patterns are not driven by a change in the types of students

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[1] Data for enrollment overall and among public 2-year colleges, which we refer to as "community colleges," in 2019 (De Brey et al., 2021; Tables 303.50 and 321.12).

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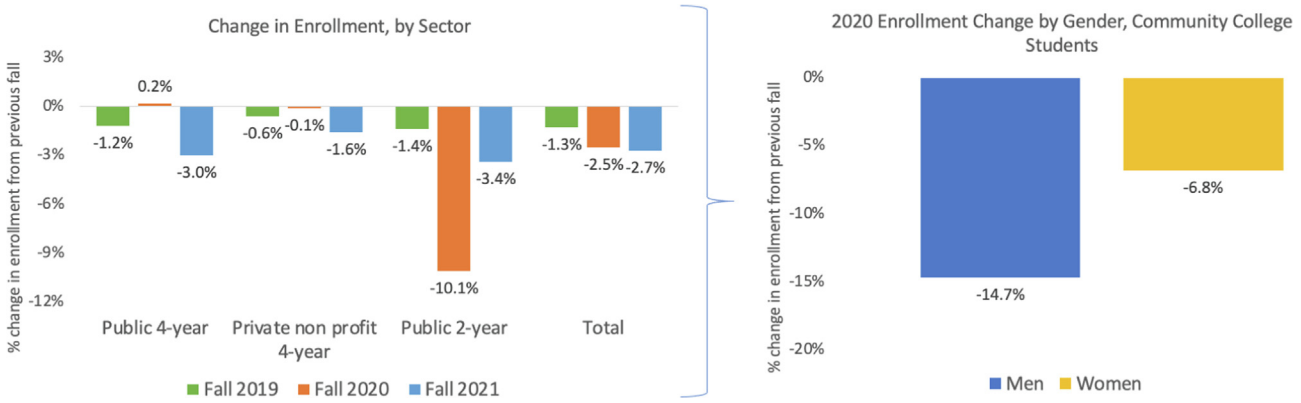

Fig. 1. Changes in Enrollment from National Data by Type of Institution Source: National Student Clearinghouse, Current Term Enrollment Estimates, Fall 2021.

enrolling in community colleges, but instead appear to be driven by institutional constraints which are more likely to bind in technical and health fields (Stange et al., 2017).[2]

Within community colleges, the disruption of the COVID era may have differentially affected programs of study, highlighting wide variation in production technologies. Because some fields have much more intensive on-site capital requirements, there may be substantial differences across programs in capacity to adjust to changes in enrollment demand. Still, many community colleges had extensive online offerings before the pandemic. Some courses in the social science or professional fields that are lecture-based or have computer-based modules, such as accounting or web design, had already been conducted online requiring little or no shift in response to COVID. Among those classes previously meeting in person, direct instruction or lecture-based courses were likely easier and less costly to shift online in response to the COVID shock. On the other hand, courses that require significant capital and "hands-on" experiential learning, such as welding or automotive repair, are likely to be least elastic in supply and most difficult to transfer to an online environment.

We investigate responses to the supply shocks induced by COVID across fields that differ in the costs (and benefits) of online or socially distanced learning, using community college administrative records from a sample of seven states, representing about half of national community college enrollment. We focus on assembly, repair and maintenance (ARM) courses of study at community colleges, which include many short-term certificate programs which require hands-on training, often use specialized equipment in "lab" or "shop" settings and are associated with above-average earnings among those with community college training. In the short-run, supply of these courses was particularly reduced by COVID—with reductions in class sizes due to social distancing requirements, or restrictions on hands-on instruction. Our empirical analysis shows that community colleges that are more intensive in the delivery of ARM skills show larger declines in enrollment, enough to explain about one-quarter of the total decline in enrollment in fall 2020. Further, since both typical enrollment in ARM fields and the COVID-era enrollment decline are particularly concentrated among men, we find that differences between men's and women's pre-pandemic enrollment in ARM coursework can explain the entire male–female gap in the enrollment decline during COVID. To complement the empirical analyses of enrollment data, we present evidence from a survey of programs focused on automotive repair training, finding evidence of the barriers to moving experiential courses online. To wit, in the words of one instructor, "It is impossible to 'teach' tire replacement through a screen.".

2. Supply-side disruptions during COVID

Community colleges, to a much greater extent than 4-year colleges, provide a wide range of instructional products that differ in their production technologies: some are lecture or discussion-based, while others involve hands-on training with specialized tools, sometimes requiring specific and costly capital inputs such as cars or HVAC systems in need of repair. Programs necessarily vary in their teaching requirements in terms of whether the material requires group interaction, whether there is a hands-on or laboratory component, and the mix of expressive versus quantitative components of coursework.

The COVID shocks to instruction, including shifts to more online instruction and social distancing requirements for in-person teaching, imposed different cost shocks across programs of study. For courses that were already offered online, the pandemic did not impact costs of instruction. For lecture- or discussion-based courses, shifts from in-person to online involved adaption to new platforms for students and faculty, but the direct costs were generally modest and limited to software and audio-visual equipment. Moreover, for a set of community college courses which overlap with those offered at four-year colleges and universities—such as mathematics, statistics, psychology, etc.—the change in cost induced by the pandemic would be expected to be similar across types of institutions. For courses that required an in-person, hands-on component, though, the increase in cost of instruction per student was generally higher, with maximum capacity in instructional spaces reduced due to social distancing requirements, and frequent, required deep cleaning of shared spaces. Note that since community colleges generally cannot charge different tuition to students taking courses that vary in their capital requirements, there was little ability to recoup these additional costs.

To illustrate, we consider course offerings in North Carolina community colleges, drawn from administrative records.[3] Compare course offerings and enrollment in "web technologies" and "welding" between fall 2019 and fall 2020 (shown in Appendix Table A1). In the baseline of fall 2019, about 75 percent of courses

[2] Constraints in offerings may also impact the extensive margin of community college enrollment. Goodman and Volz (2020) show that variation in state appropriations to public colleges shifted enrollment to the for-profit sector. Similarly, Cellini (2009) finds that when community colleges are able to increase supply due to passage of bond referenda, enrollment shifts from the for-profit to the public sector.

[3] Among states with available enrollment data, North Carolina is the only state with publicly available course-level data available on mode of instruction. Similar data are also available for Texas on a restricted access basis through their Education Research Centers.

in web technologies were already conducted entirely online. On the other hand, only 15 percent of welding courses had *any* online component prior to COVID. With the onset of COVID, in fall 2020 the share of courses with an online component increased in both programs: to 99 percent for web technologies, and 63 percent for welding. For web technologies, total enrollment increased but fewer courses were offered, increasing average class size and presumably reducing costs per student. For welding, total enrollment fell but the number of courses taught remained essentially the same, and class size fell—likely reflecting the requirements for social distancing for in-person components. In the near term, costs of delivery for welding courses likely increased with COVID given the reductions in class size and the costs of developing hybrid modes of delivery. As a result, colleges may have had binding capacity constraints because of their inability to increase supply quickly.

Programs that, like welding, require extensive on-site instruction and physical capital components are particularly likely to have experienced large increases in costs of delivery during COVID. These "supply-side" disruptions, generated when training is capital-intensive and necessarily experiential, are likely to vary with the degree mix offered by community colleges, while also having a disparate impact for men to the extent that men are more likely to pursue occupational training involving heavy machinery and requiring "hands-on" skills.

3. Empirical strategy and data

Ideally, we would observe supply-side disruptions directly, including those that impacted entire community colleges and those that were specific to fields of study. While we observe information on the dominant mode of operation at all community colleges, in most states we do not observe format of instruction across programs either before or after COVID. Instead, we identify courses of study that are likely to be intensive in the use of on-site capital and "hands-on" training, which we refer to as assembly, repair and maintenance (ARM) programs, by connecting courses of study to their associated jobs and identifying jobs that require hands-on skills. To do so, we connect O*net classifications of skills needed for specific occupations to 4-digit program of study (CIP) codes.

We define a course of study to be an ARM field if its associated O*net job title requires skill in repairing, equipment maintenance, equipment selection, or operation and control (see Appendix A for details of coding). It is plausible that the training requirements in these fields made it particularly difficult and costly to adapt to COVID. We then use variation across community colleges in the percentage of certificates and degrees in ARM programs prior to COVID to explain variation in community college enrollment between 2019 and 2020, as well as the relative decline in enrollment of men compared with women.

"Supply disruptions" brought about by COVID restrictions are hypothesized to have had a substantial impact on the provision of ARM coursework because of the importance of hands-on laboratory work in these programs of study. Social distancing requirements reduced the number of people who could be in a lab at the same time, and in places with shutdowns in effect the lab component may have been eliminated entirely—which in turn may have required courses to be canceled or postponed if the lab component was required for licensure.

To explore the extent to which declines in ARM coursework contributed to the overall decline, we require timely data on course enrollment at community colleges. Unfortunately, the availability of data at the level of community colleges with detail on student demographics and courses of study is limited, and the federal administrative survey data (IPEDS) on enrollment at community colleges is only available with a substantial lag (and the final release for fall 2020 enrollment was not available in October of 2021). To fill this gap, we collected enrollment data by sex for fall 2020 at the community college level from seven individual states (CA, IL, MA, NC, TN, TX, VA) which represent about 50 percent of national 2-year college enrollment.[4] Overall enrollment declined by about 15 percent in 2020 in these states (Table 1). The enrollment of men was down more than 20 percent in 2020, while the enrollment of women declined by about half as much; neither group had a substantial change the prior year.

For each community college, we also collected data on the county-level unemployment rate, as well as the delivery status during COVID, categorizing them as fully online, fully in-person, or hybrid delivery. We use the federal administrative data collection to measure "baseline" (pre-COVID) course offerings. The 2018 IPEDS data provide information on the distribution of degrees by field (CIP codes) and award level (<1 year certificate, 1–2 year certificate, AA degree), and indicators for whether the program was offered online in the pre-COVID period.

We examine the relationship between COVID-era changes in enrollment (fall 2020 vs. fall 2019) and the baseline share of degrees/certificates awarded in ARM fields (*%ARM*). The primary specification is:

$$d \ln E_{sj} = \alpha + \beta ARM_{j18} + \varepsilon_{sj}$$

where $d \ln E$ represents the year over year change in log enrollment, with s indicating the sex of the student population and j indexing individual community colleges. Alternative specifications add state fixed effects, county unemployment rates, and community college-level instruction mode during COVID (in-person, online, or hybrid). Results are weighted by baseline enrollment levels.[5] The coefficient of interest (β) indicates the extent to which a greater representation of baseline ARM enrollment yields a larger (hypothesized to be negative) change in enrollment in the COVID era. We estimate the same specification for the pre-COVID period (2018 vs. 2019) as a falsification test, expecting that the baseline ARM share is unrelated to previous year-to-year changes in enrollment.

Table 1 shows descriptive statistics of our community college sample. Overall, 12 percent of certificate and degree program awards are categorized as ARM programs in our analysis sample of community colleges.[6] There is significant variation across community colleges in the share of certificates and degrees awarded in ARM fields, with the interquartile range spanning 4 percent to 17.6 percent. This variation also occurs within states and is plausibly tied to local economic conditions. To illustrate, Austin Community College which serves the tech corridor in the Austin metro area has an ARM share of 7.5 percent while South Plains College (Levelland, TX) where the community is relatively rural and focused on farming and petroleum has and ARM share of about 20 percent. Similarly, De Anza College is Cupertino (home of Apple) has an ARM share of 6.6 percent which is much lower than the ARM share of 21 percent for Columbia Community College in Sonora (in the Sierra Nevada Foothills).

Credential receipt in ARM fields at community colleges is overwhelmingly male and this is true across broad field categories such

[4] These states were selected because they either posted data in the summer of 2021 or released data in response to direct outreach. Data for several additional states such as Connecticut were available but did not include data disaggregated by gender. Bulman and Fairlie (2021) provide early descriptive evidence of the pattern of enrollment decline at California post-secondary institutions.

[5] Unweighted regressions are qualitatively similar and are available upon request.

[6] A histogram of the distribution in baseline ARM enrollment is shown in Appendix Fig. A1.

Table 1
Summary statistics, community college enrollment sample.

	Overall		Men		Women	
	Mean	sd	Mean	sd	Mean	sd
	(1)	(2)	(3)	(4)	(5)	(6)
% Ch Enroll 2020–2019	−0.150	0.115	−0.208	0.136	−0.105	0.109
% Ch Enroll 2019–2018	−0.004	0.052	−0.011	0.058	0.001	0.055
Unemployment Rate 2020	11.4	3.3				
Unemployment Rate 2019	4.1	1.5				
% Cert-Deg ARM	0.117	0.098	0.221	0.163	0.029	0.028
% Cert-Deg Online	0.196	0.250	0.176	0.224	0.214	0.275
Primary Instructional Mode						
Hybrid	0.099	0.299				
In-Person	0.057	0.233				
Online	0.843	0.364				
Observations	318		318		318	

Notes: Data on enrollment and degrees are recorded at the level of the community college and weighted by 2019 enrollment. Enrollment data in the analysis sample (CA, IL, MA, NC, TN, TX, VA) reflect community college enrollment levels reported to states. "% Cert-Deg ARM" indicates the share of certificates and AA degrees awarded in "Assembly, Repair and Maintenance" fields at the community college from IPEDS in the 2017–18 academic year. Designation as "Hybrid", "In-Person", "Online" indicates the overall institutional mode of delivery in fall 2020. See Data Appendix for additional details.

construction trades (94% male), mechanic and repair technologies (94%), precision production (93%) and transportation (88%); see Appendix Table A2. Most of the credentials awarded in these areas are short-term certificates, requiring less than the two years of study needed for Associates level degrees. IPEDS data that record whether programs within a CIP code can be completed entirely via distance education show that very few ARM programs of study—about 1%—were offered entirely online in baseline data, while more than 20% of programs in areas like education, area studies and general studies were offered online (Appendix Table A2).

The impact of COVID restrictions and labor market responses varied both across states and, within states, across community colleges. As part of national efforts to classify COVID responses of post-secondary institutions, institutions were classified in terms of their overall opening status in Fall 2020. The magnitude of the shift in instructional delivery is marked: 84 percent of students in our analysis sample were enrolled in community colleges reporting that classes were taught in a primarily online setting in response to COVID, and only six percent of students attended community colleges reporting primarily in-person instruction. Communities faced considerable variation in the impacts of COVID on economic activity, thought virtually all community college markets faced increases in unemployment between 2019 and 2020. The county-level unemployment rate was 4.1 percent averaged over June-August 2019, and rose to 11.4 percent in the same months in 2020. In the COVID context, changes in the unemployment rate may represent not only an indicator for the canonical opportunity cost of enrollment but may also indicate other local conditions (such as stay-at-home mandates or school closures) impacting enrollment. An important observation for identification is that the county-level change in the unemployment rate is broadly uncorrelated with the baseline ARM share.

4. Estimation results

Our interest is in testing the extent to which the difference in "product bundles," specifically the concentration of credential awards in ARM fields, explains the observed variation in COVID-era enrollment declines across institutions and gender groups. Table 2 shows the relationship between pre-COVID ARM enrollment and the log change in community college enrollment between 2020 and 2019, in regressions weighted by enrollment and controlling for state fixed effects to account for state-level policy responses to the pandemic such as closures which might impact enrollment.[7] As shown in column (1), the difference between having 0 and 100 percent ARM credential concentration predicts about a 40 percent decline in enrollment during COVID. Since the mean level of ARM enrollment is 0.105, this implies that concentration in ARM programs explains about 28% of the observed decline in enrollment between 2019 and 2020.

Adding controls for the reported institution-wide primary mode of instruction demonstrates that, relative to in-person delivery, hybrid and online delivery are associated with 4–5 percent lower enrollment net of state fixed effects (column 4). Adding mode of delivery controls to the specification does not appreciably change the ARM coefficient.[8] Unlike prior recessions, local economic conditions as represented by the change in the unemployment rate do not have a meaningful impact on enrollment.

To what extent does differential representation in ARM fields explain differences in the COVID-era enrollment decline between men (21%) and women (11%)? If we assume a common effect of the ARM concentration from column (1) of about −0.4, differences in ARM enrollment by gender predict a differential enrollment change of about −0.093—more than 90% of the observed difference in enrollment decline.

We test directly the extent to which ARM may have different impacts for men's and women's enrollment in the additional columns of Table 2. The magnitude of the effect is somewhat larger for men than for women: −0.5 vs. −0.3. Using the gender-specific estimates from Table 2, the relative concentration of men in ARM fields still explains 70% of the overall difference between men's and women's enrollment declines.

The regression results illustrate that community colleges with a higher share of ARM enrollment experienced greater enrollment reductions in the COVID era. We interpret these as consistent with disproportionate "supply side" shocks in these fields, since

[7] Results are qualitatively similar without state fixed effects. In our coding, we have explored the use of both 2-digit and 4-digit CIP codes. We focus on the 4-digit CIP codes as there is likely less measurement error in the alignment of task composition and subject matter at this level. For example, the 2-digit CIP code approach defines all courses of study under code 15, Engineering/Engineering-Related Technologies/Technicians, as ARM. In the 4-digit approach, it distinguishes that 15.13 (Drafting/Design Engineering Technologies/Technicians) and 15.16 (Nanotechnology) are not ARM, while other courses are such as 15.06 (Industrial Production Technologies/Technicians) and 15.09 (Mining and Petroleum Technologies/Technicians).

[8] In specifications not shown, we also interacted the ARM measure with the Fall 2020 delivery mode and we did not identify significant effects.

Table 2
Community college enrollment changes 2019–2020.

VARIABLES	(1) Overall	(2) Men	(3) Women	(4) Overall	(5) Men	(6) Women
% ARM	−0.407	−0.523	−0.293	−0.411	−0.529	−0.297
	(0.040)***	(0.049)***	(0.026)***	(0.034)***	(0.042)***	(0.026)***
Hybrid				−0.043	−0.042	−0.041
				(0.016)**	(0.026)	(0.014)**
Online				−0.050	−0.065	−0.038
				(0.009)***	(0.024)**	(0.009)***
Unemp. Rate				0.002	0.004	−0.000
				(0.003)	(0.005)	(0.002)
Constant	−0.147	−0.209	−0.102	−0.111	−0.184	−0.062
	(0.003)***	(0.004)***	(0.002)***	(0.027)***	(0.049)***	(0.023)**
Observations	318	318	318	318	318	318
R-squared	0.228	0.228	0.165	0.237	0.241	0.172
Weights	Yes	Yes	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.
Notes: Dependent variable is the ln difference in enrollment 2020–2019; "% ARM " indicates the share of certificates and AA degrees awarded in "Assembly, Repair and Maintenance" fields at the community college from IPEDS in the 2017–18 academic year. Designation as "Hybrid", "In-Person", "Online" indicates the overall institutional mode of delivery in fall 2020. See Data Appendix for additional details.

programs that emphasize tactile learning and generally require on-site lab or shop courses are most difficult to shift online.[9]

While the shift to a fully online or hybrid format in response to COVID-19 was particularly stark, online education is by no means new to community colleges. In 2018, 36.8 percent of community college students took an online course, and about 15 percent took all their courses online (De Brey et al., 2021, Table 311.15). The pre-COVID adoption of online education varies markedly across institutions, with some institutions offering only a small fraction of credentials online and other institutions offering many credentials entirely online (see Appendix Fig. A2). If schools with more prior experience with online delivery were able to more successfully adapt to online provision during COVID, we would expect to see differences in enrollment changes related to the prior provision of online courses. While the community college-level share of credentials awarded online at baseline appears to attenuate enrollment declines, the positive coefficient is not significant at conventional levels (Appendix Table A4). Similarly, there is no significant effect on an interaction between this baseline online share and the ARM variable. Thus, our evidence does not support the hypothesis that institutional-level differences in facility with online technologies predicts enrollment responses to the COVID disruption.

A different type of threat to validity derives from the concern that enrollment in ARM fields may have been declining prior to 2020, perhaps reflecting a secular trend that would have continued in the absence of COVID. We test this, repeating the analysis for enrollment changes in the prior year (2018 to 2019), in Appendix Table A3. Across the board, there is no impact of ARM shares on the pre-COVID enrollment change, nor is mode of delivery adopted during COVID related to the observed enrollment changes, overall or separately by gender.

5. Case study: Automotive service credentials

Community college programs in automotive repair fields, which are among the ARM fields, are often accredited by the Automotive Service Excellence Education Foundation (ASE), an industry group that tests and certifies auto mechanics.[10] In December of 2020, ASE surveyed instructors across community colleges on their experiences during COVID, providing both quantitative and qualitative indicators of how program delivery was impacted by pandemic circumstances.

The ASE survey was conducted in December 2020, and included responses from 287 instructors at community colleges, representing a 37.3 percent response rate. The survey asked for program enrollment at various dates (April 1, July 1, and October 1, in 2019 and 2020), as well as mode of instruction (in-person only, online synchronous only, online asynchronous only, hybrid) in 2019 and 2020, and the instructor's perception of the importance of various barriers (having COVID, childcare, etc.) to changes in enrollment. Every instructor also provided an open-ended response to a question asking how COVID-19 affected instruction and learning in courses with a hands-on or lab component, which we coded using qualitative NVivo software.

Average reported enrollment in automotive repair courses taught by instructors in the survey was 133 in October 2019 and fell by 19 percent to 108 in October 2020.[11] Instructors also reported dramatic shifts in the mode of instruction between 2019 and 2020. Prior to COVID, fully 72 percent of respondents reported their courses were offered entirely in-person; in 2020, 15 percent reported their courses were conducted entirely in person (representing respondents from 27 states) while 8 percent reported that their courses were entirely online (with these responses clustered in CA, OR and PA).[12] Descriptive regression results indicate that those programs that showed the largest changes in mode of delivery—essentially shifting from in-person to an online synchronous or asynchronous mode of instruction—had the largest declines in enrollment. And, while any online delivery was relatively rare in

[9] It is unlikely that students seeking to study ARM subjects instead attend for-profit institutions, which experienced a modest year-over-year enrollment increase in spring 2021 and essentially no change in the fall of 2020. Pre-pandemic, more than 75% of less than two-year credentials in ARM fields were awarded by public institutions, indicating that these institutions hold the majority of training capacity in these programs (De Brey et al., 2021, Table 320.10).

[10] Specifically, automotive repair is found under the broad heading "Mechanic and Repair Technologies / Technicians" (47) in the CIP taxonomy. The 4-digit CIP "47.06 Vehicle Maintenance and Repair Technologies" includes 18 6-digit headings including 47.0600 Vehicle Maintenance and Repair Technologies, General, 47.0603 Autobody/Collision and Repair Technology/Technician, 47.0604 Automobile/Automotive Mechanics Technology/Technician, 47.0605 Diesel Mechanics Technology/Technician, etc.

[11] Spring enrollment (April) was nearly identical to fall enrollment, averaging 129 in 2019 and 115 in 2020. Summer enrollment averaged 92 in summer 2019 and fell to 76 in summer 2020.

[12] Prior to COVID, 87% of courses were offered entirely in person, while after COVID 32% were.

2019, those institutions that had established partial online delivery in 2019 had somewhat smaller declines in enrollment between 2019 and 2020.[13] As noted by ASE leadership, programs that used online tools in the baseline found it easier to pivot online during the pandemic because the curriculum (and all the exercises and assessments) were already set up online, effectively saving the on-campus time for hands-on practice in the lab.

Because the ASE survey data only present information on the percent distribution of course offerings, we turn to administrative data from course offering aligned with certificate and degree programs in ASE accredited programs North Carolina to better understand the connection between mode of delivery and enrollment in response to the pandemic-related shock. Two of the most common courses required for automotive credentials are "Engine Repair" (AUT116, covering the theory, construction, inspection, diagnosis, and repair of internal combustion engines and related systems) and "Basic Transportation Electricity" (TRN120, covering basic electrical theory, wiring diagrams, test equipment, and diagnosis, repair and replacement of batteries, starters, and alternators). These courses often combine practical applications and basic science that is covered in the lecture portion of the course—for example, Ohm's Law about the connection among voltage, current and resistance is part of the required course on electricity. Thus, it is quite plausible that part of the course material could be presented online in either a synchronous or asynchronous format, but the "hands-on" part of the experience is likely difficult to replicate outside of the on-site delivery.

In the fall of 2019, all but 1 of the 46 class offerings of AUT-116 at nine North Carolina community colleges were offered in a "Traditional" or fully in-person format, with the single outlier offered in a "blended" format (<50% online). For TRN-120, only 3 of the 46 class offerings were in a format other than traditional, with the three offered in the blended format. With the arrival of the pandemic in the fall of 2020, nearly two-thirds of the TRN-120 and AUT-116 courses were in a partially online format—either blended or hybrid (51–99% online).

In core courses that are part of the automotive credential sequence, the onset of COVID brought a shift to partial online delivery in these courses, though none went fully online. Notably, ASE deployed resources intended to help instructors preserve instructional quality while navigating COVID, including advice on which parts of coursework are best suited to e-learning in a hybrid setup, links to pre-produced e-learning modules for instructors and students, and ongoing additional technical update webinars during COVID for instructors.[14] Even prior to COVID, a small share of auto repair instructors had already included some online learning component in their courses, typically offering textbook or "theory" components in a synchronous or asynchronous online component, and sometimes doing the initial demonstration of how to perform a particular task online (to be followed by students' own hands-on practice of that task in the lab).[15] This shift will likely be permanent in many cases, with impacts on learning that could be positive (e.g., if students respond well to self-pacing) or negative (e.g., if students are less engaged with online than in-person instruction).

In the open-ended questions about the impact of COVID on their courses, instructors described many ways that supply was limited, instruction costs increased, and students were affected by the changes brought during COVID. Thirty percent of respondents mentioned that their allowable class sizes were reduced, particularly for the lab portion of the course and generally due to the need to socially distance. Three percent volunteered that some classes were canceled entirely due to constraints on the availability of lab space. One in five respondents mentioned the additional costs due to the need to sanitize workspaces, socially distance class members, and/or mask. Many instructors reported a shift in mode toward more online learning—many expressing frustration with the need to suddenly record and edit videos—with about eleven percent reporting that their students had less hands-on time in the laboratory and seven percent reporting that hands-on work was eliminated entirely in some courses where this was permissible under accreditation rules.

There were several lines of responses that suggested that students were learning less or more disengaged due to COVID changes. One common response indicated that the normal pedagogical flow of learning was disrupted, and made worse, due to COVID. In some cases, due to limitations on access to lab space, labs needed to be scheduled to be performed prior to the related classroom instruction component. In other cases, labs were condensed into a shorter time period out of concern that the instructional period would have to be curtailed in response to rising COVID cases. Some instructors found a silver lining in the changes. For example in colleges that did not allow students to work in groups, some instructors believed that the individual hands-on practice improved students' understanding.

Many instructors lamented a decline in student engagement and morale, reporting that their students are generally hands-on learners, and noting that it has been particularly challenging to engage them and instruct them online. One instructor noted that "shop sessions that are socially distanced are of lower value to tech students." Another remarked "I can't 'teach' online what things look, sound, feel, smell like." Instructors report high levels of student disengagement and course failure.

Overall, instructors in automotive repair and maintenance recognize that their courses use different technologies and have had to respond differently to COVID than subjects where classroom presentations and lectures are the norm. One instructor remarked "the skilled trades programs have pretty much been the only ones on campus. Liberal arts has been nowhere to be found." The qualitative and quantitative evidence makes clear that shifting to a fully online mode of delivery differed dramatically in feasibility across programs of study at community colleges.

6. Discussion and conclusions

Community colleges in the U.S. serve a wide range of student needs, ranging from traditional liberal arts and general studies degrees that generate credits that can be transferred to baccalaureate degree programs to very short-term vocational certificates that are directly connected to occupational trajectories. Within this portfolio of skill development programs, there are a wide range of pedagogical models and differences in costs of instruction. Some of this variation is tied inherently to the nature of learning in different fields. Social distancing requirements generated by the COVID pandemic thus had vastly different implications across programs of study. Programs that require "hands on" learning leading to skilled trade work were much more impacted than those emphasizing abstract skills or those in which the work could be done primarily online.

Our results are unambiguous in identifying the production technology in ARM fields, which were more costly to adjust to the disruptions of COVID, as a contributing factor to COVID-era enrollment declines, accounting for about 20% of the overall decline. This factor explains almost all the greater decline in the

[13] Results are presented in Appendix Table A4 and robust to the inclusion of state fixed effects.

[14] In addition, as the accreditor they offered flexibility in some program requirements and an extended testing window for students seeking ASE's entry-level certification credential.

[15] There is a required number of hours of classroom and lab time for a program to be accredited; a maximum of 25 percent of these hours can typically be performed via e-learning outside of normal class or lab time.

enrollment of men relative to women during the COVID period. To be sure, our analysis of ARM fields only captures a portion of courses that are hard to substitute online in the short run. While we focus on ARM due to our ability to link jobs requiring particular hands-on skills to their related courses of study, there are surely other fields that also experienced large supply-side interruptions. For example, personal and culinary services, which represents about 1 percent of community college enrollment, also experienced a 17 percent decline in enrollment in 2020 according to National Student Clearinghouse data.[16]

It is nonetheless important to be forthright that the supply-side disruptions that we identify in this paper are but one of the factors that impacted the learning trajectories of young adults during the COVID era. Other potentially relevant explanations on the demand side for the decline in community college enrollment include the substantially increased burden on families created by childcare and home school needs and the limited access to broadband and other online learning tools. But these factors generally do not disproportionately impact men, and do not account for the large gender differences in enrollment observed during COVID.

These results, which highlight the variation across programs at community colleges in production technologies and supply elasticity, have substantial implications for labor markets and education policy design. If we consider the COVID disruptions to the production of ARM credentials to be a "supply shock" to the education market, it is likely that there will be near-term implications for the labor market in terms of "supply chain disruptions" in the flow of newly trained workers to local labor markets. Demand for skills in fields like HVAC repair, welding and auto repair is unlikely to have abated during the pandemic—and in the case of HVAC repair likely grew in response to improved ventilation recommendations—while the flow of new workers has been disrupted.

Meaningful differences across programs of study within institutions—particularly in community colleges—in "production technologies" and costs have implications for policy design.[17] Public polices such as free tuition or headcount-based appropriations create incentives for expansion of programs of study that can be produced at a low cost or expanded at a low marginal cost. The result may be supply-side offerings that are poorly aligned with student demand and labor market needs. The result may be persistent excess demand in high-return fields where capital equipment and on-site training are necessary for skill acquisition.

Looking ahead, the disruption of the pandemic may induce important technological change in the production of post-secondary education across fields. In response to the COVID experience, more colleges may expand their online offerings and invest in new simulation technologies to broaden the types of courses that can be offered online. The extent to which these potential shifts will be able to engage students who are tactile learners is an open question.

A survey of career and technical education programs at community colleges by researchers at the Urban Institute identified shifts in mode of delivery across career and technical education fields (Briggs et al., 2021). All fields saw a sharp decline in the share of courses delivered in person during fall 2020, though programs related to ARM (manufacturing technologies, HVAC servicing and auto repair) saw smaller drops than other fields (such as licensed practical nursing and early childhood education, see Appendix Table A7). While respondents predicted a partial rebound in in-person instruction after the pandemic, they also predicted a shift to more hybrid instruction. While it was difficult (and often cost prohibitive) to introduce simulation technologies in ARM fields in the pre-pandemic era, some programs expect to adopt simulation technologies and online learning tools which will likely persist post-COVID. Shifting to hybrid models in which classroom instruction is largely virtual provides community colleges with some cost-savings in terms of both fixed and variable classroom costs, while potentially adding some benefits of self-paced learning and an increased ability to reach students for whom in-person instruction is more costly due to factors such as travel costs. Thus, a silver lining of the pandemic disruptions is that they may provide some of the impetus to adopt new instructional technologies, eventually "bending the cost curve" to reduce the expense of program delivery in fields that have traditionally required fully on-site instruction.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Sarah Turner reports funding was provided by the Smith Richardson Foundation.]

Appendix A

See the Figs. A1–A2 and Tables A1–A7.

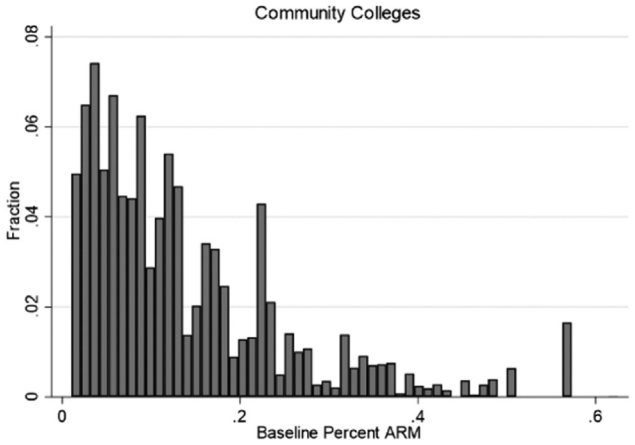

Fig. A1. Pre-period (2019) Variation in Assembly, Repair & Maintenance (ARM) Enrollment, Full U.S. Universe of Community Colleges.

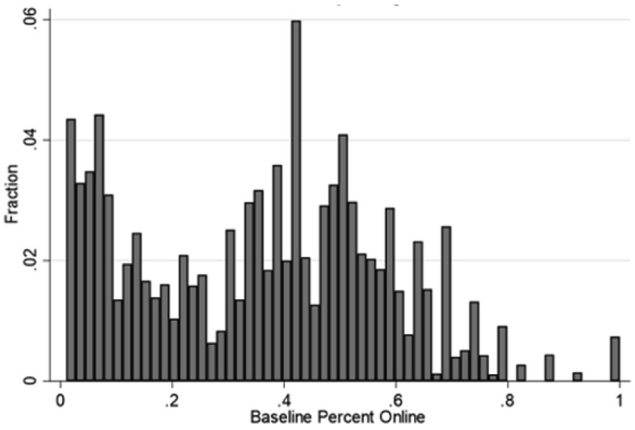

Fig. A2. Pre-period (2019) Online Education Distribution, Full Universe of Community Colleges Source: Authors' tabulations from IPEDS (2018).

[16] Appendix Table A6 shows percentage change in fall enrollment relative to the prior fall from National Student Clearinghouse reports on Current Term Enrollment Estimates for 2020 and 2021 at the 2-digit CIP level. Many of the ARM fields had increased enrollment in fall 2021.

[17] Hemelt, Stange, Furquim, Simon and Sawyer (forthcoming) provide extensive evidence of variation in cost of instruction across different programs of study in the four-year sectors, with large differences in costs across areas of study, with engineering and nursing fields at the top of the cost ladder and fields like sociology and mathematics at the bottom.

Table A1
Mode of course instruction, welding and web technologies, North Carolina Community Colleges.

	Welding		Web technologies	
	Fall 2019	Fall 2020	Fall 2019	Fall 2020
	(1)	(2)	(3)	(4)
Panel A: Enrollment				
0% online	84%	37%	6%	1%
<=50% online	14%	50%	11%	7%
51–99% online	1%	9%	7%	4%
100% online	1%	4%	76%	88%
Total students	8859	7206	1569	1605
Panel B: Number of courses				
0% online	85%	36%	8%	1%
<=50% online	13%	51%	10%	10%
51–99% online	1%	9%	8%	6%
100% online	0.5%	3%	75%	83%
Total courses	882	869	173	155

Source: North Carolina Community College system administrative data.

Table A2
Characteristics of fields, community colleges.

	Percent Cred. Certificate	Percent Cred. Online	Percent Cred. Men
Agriculture & Related Sci	0.485	0.041	0.618
Natural Resources & Conservation.	0.280	0.029	0.681
Architecture & Related Services.	0.385	0.039	0.647
Area, Ethnic, Cultural, & Gender Studies.	0.152	0.296	0.409
Communication, Journalism, & Related Programs.	0.191	0.038	0.457
Communications Tech & Support Services.	0.519	0.036	0.629
Computer & Info Sciences & Support Services.	0.549	0.298	0.780
Personal & Culinary Services.	0.779	0.010	0.255
Education.	0.351	0.278	0.100
Engineering.	0.077	0.012	0.839
* Engineering Technologies/Technicians.	0.580	0.056	0.864
Foreign Languages, Literatures, & Linguistics.	0.424	0.042	0.207
Family & Consumer Sciences/Human Sciences.	0.706	0.191	0.060
Legal Professions & Studies.	0.426	0.112	0.157
English Language & Literature/Letters.	0.143	0.217	0.334
Liberal Arts & Sci, Gen Studies & Humanities.	0.183	0.446	0.378
Library Science.	0.671	0.298	0.189
Biological & Biomedical Sciences.	0.051	0.052	0.323
Mathematics & Statistics.	0.047	0.068	0.698
* Military Technologies.	0.006	0.899	0.771
Multi/Interdisciplinary Studies.	0.084	0.101	0.429
Parks, Recreation, Leisure, & Fitness Studies.	0.194	0.051	0.512
Philosophy & Religious Studies.	0.016	0.022	0.653
Physical Sciences.	0.037	0.046	0.573
Science Technologies/Technicians.	0.435	0.012	0.668
Psychology.	0.014	0.128	0.237
Security & Protective Services.	0.506	0.190	0.633
Public Administration & Soc Service Professions.	0.268	0.123	0.174
Social Sciences.	0.023	0.192	0.354
* Construction Trades.	0.821	0.010	0.942
* Mechanic & Repair Technologies/Technicians.	0.796	0.009	0.940
* Precision Production.	0.901	0.003	0.933
* Transportation & Materials Moving.	0.925	0.007	0.886
Visual & Performing Arts.	0.518	0.153	0.415
Health Professions & Related Clinical Sciences.	0.558	0.078	0.177
Business, Mngt, Marketing, & Related Support Services.	0.435	0.392	0.384
History	0.005	0.083	0.637

Notes: * indicates ARM field. Authors' tabulations from 2018 IPEDS Degrees Conferred data.

Table A3
Community college enrollment changes 2018–2019.

VARIABLES	(1) Overall	(2) Men	(3) Women	(4) Overall	(5) Men	(6) Women
% ARM	−0.031	−0.030	−0.028	−0.036	−0.034	−0.034
	(0.027)	(0.029)	(0.027)	(0.024)	(0.026)	(0.023)
Hybrid				0.003	−0.007	0.011
				(0.023)	(0.034)	(0.013)
Online				−0.007	−0.016	−0.001
				(0.019)	(0.027)	(0.012)
Unemp. Rate				−0.001	−0.001	−0.001
				(0.001)	(0.001)	(0.001)
Constant	−0.010	−0.015	−0.006	0.010	0.013	0.009
	(0.002)***	(0.002)***	(0.002)**	(0.019)	(0.025)	(0.016)
Observations	318	318	318	318	318	318
R-squared	0.185	0.151	0.175	0.193	0.159	0.183
Weights	Yes	Yes	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.
Notes: Dependent variable is the ln difference in enrollment 2020–2019; "% ARM" indicates the share of certificates and AA degrees awarded in "Assembly, Repair and Maintenance" fields at the community college from IPEDS in the 2017–18 academic year. Designation as "Hybrid," "In-Person," "Online" indicates the overall institutional mode of delivery in fall 2020. See Data Appendix for additional details.

Table A4
Community college enrollment changes 2019–2020, Including Prior Online Exposure.

VARIABLES	(1) Overall	(2) Men	(3) Women	(4) Overall	(5) Men	(6) Women
% ARM	−0.408	−0.523	−0.296	−0.395	−0.531	−0.259
	(0.038)***	(0.050)***	(0.029)***	(0.064)***	(0.082)***	(0.035)***
Hybrid	−0.043	−0.042	−0.042	−0.042	−0.043	−0.040
	(0.016)**	(0.026)	(0.015)**	(0.017)**	(0.027)	(0.015)**
Online	−0.051	−0.068	−0.039	−0.051	−0.068	−0.038
	(0.007)***	(0.020)**	(0.010)***	(0.007)***	(0.021)**	(0.011)**
Unemp. Rate	0.002	0.004	−0.000	0.002	0.004	−0.000
	(0.003)	(0.005)	(0.002)	(0.003)	(0.005)	(0.002)
% Cert Deg Online	0.014	0.033	0.007	0.027	0.025	0.041
	(0.026)	(0.032)	(0.026)	(0.038)	(0.063)	(0.023)
% Online * % ARM				−0.130	0.085	−0.346
				(0.316)	(0.436)	(0.230)
Constant	−0.112	−0.184	−0.062	−0.113	−0.183	−0.066
	(0.027)***	(0.047)***	(0.023)**	(0.023)***	(0.045)***	(0.020)**
Observations	318	318	318	318	318	318
R-squared	0.237	0.243	0.172	0.238	0.243	0.174
Weights	Yes	Yes	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.

Table A5
Effects of Instruction Mode on Enrollment Changes, Automotive Service Excellence Data, 2020–2019.

	(1)	(2)	(3)	(4)	(5)
Ch Asynchronous online	−0.387**	−0.345**	−0.358**		−0.397*
	(0.159)	(0.173)	(0.155)		(0.207)
Ch Synchronous online	−0.416***	−0.316**	−0.420***		−0.1400
	(0.133)	(0.139)	(0.130)		(0.177)
Ch Hybrid	−0.100***	−0.0817*	−0.106***		−0.154**
	(0.038)	(0.045)	(0.039)		(0.063)
Asynchronous online 2019				−0.7450	−0.9200
				(1.037)	(0.952)
Synchronous online 2019				0.453***	0.311**
				(0.125)	(0.140)
Hybrid 2019				0.0738	−0.0829
				(0.101)	(0.105)
Student/family had COVID			−0.0178	−0.0122	0.0272
			(0.117)	(0.127)	(0.119)
Had to care for child/sibling			0.0263	0.0245	0.0699
			(0.092)	(0.109)	(0.097)
Students uncertain a/b program changes			0.0214	0.0117	0.0681
			(0.100)	(0.105)	(0.103)
Unable to pay for courses b/c lost income			0.0361	0.0098	0.0984
			(0.130)	(0.148)	(0.131)
Constant	−0.122***	−0.560	−0.272***	−0.412***	−0.304***
	(0.024)	(0.000)	(0.102)	(0.109)	(0.110)
State FE	N	Y	Y	Y	Y
Observations	287	287	287	287	287
R-squared	0.110	0.293	0.127	0.249	0.291

Notes: Authors' tabulations from ASE Survey. See Data Appendix.

Table A6
Percentage change in fall enrollment relative to prior fall, 2-year institutions.

	2021	2020
ARM-related		
Construction Trades	17.5%	−10.9%
Engineering Technologies and Engineering-Related Fields	1.5%	−14.5%
Mechanic and Repair Technologies/Technicians	7.0%	−15.9%
Precision Production	9.9%	−18.4%
Transportation and Materials Moving	13.7%	−10.8%
Other		
Agriculture, Agriculture Operations, and Related Sciences	40.8%	−2.2%
Architecture and Related Services	5.8%	−1.7%
Biological and Biomedical Sciences	−5.6%	−1.2%
Business, Management, Marketing, and Related Support	−0.6%	−9.2%
Communication, Journalism, and Related Programs	−9.3%	−11.6%
Communications Technologies/Technicians and Support Services	−1.0%	−16.2%
Computer and Information Sciences and Support Services	2.9%	−4.2%
Education	−3.5%	−6.7%
Engineering	−3.6%	−9.3%
English Language and Literature/Letters	−8.3%	−14.3%
Family and Consumer Sciences/Human Sciences	−3.0%	−11.6%
Foreign Languages, Literatures, and Linguistics	−4.6%	−5.0%
Health Professions and Related Programs	−2.2%	−2.3%
History	−2.2%	−3.9%
Homeland Sec., Law Enf., Firefighting, and Related Protective Svcs	−7.4%	−14.7%
Legal Professions and Studies	1.2%	−2.4%
Liberal Arts and Sciences, General Studies and Humanities	−5.0%	−11.9%
Mathematics and Statistics	−12.6%	−8.5%
Multi/Interdisciplinary Studies	−2.1%	−12.6%
Natural Resources and Conservation	0.4%	−2.0%
Parks, Recreation, Leisure and Fitness Studies	−4.6%	−6.7%
Personal and Culinary Services	6.2%	−17.2%
Physical Sciences	−17.5%	−17.3%
Psychology	1.6%	4.4%
Public Administration and Social Service Professions	−2.3%	−5.4%
Science Technologies/Technicians	−2.7%	−2.6%
Social Sciences	−7.4%	−9.8%
Visual and Performing Arts	0.6%	−14.2%

Source: National Student Clearinghouse, *Current Term Enrollment Estimates – Fall 2021*, Table 11.

Table A7
Delivery Status of Career and Technical Education Programs Before, and During the Pandemic, and Expected After the Pandemic.

	Share Delivered in Person			Expected Changes: 2019 to 2021	
	Fall 2019	Fall 2020	Fall 2021 (expected)	In-person to hybrid	Hybrid to in-person
Programs related to ARM:					
Auto repair	78	28	68	18	8
Welding	71	37	63	16	8
HVAC	62	23	44	26	8
Manufacturing	48	11	24	28	4
Other programs:					
Licensed practical nursing	57	5	35	30	8
Early Childhood Education	24	4	15	11	2
Information technology	5	3	5	5	5
Business administration	3	3	5		

Source: Briggs et al., 2021.
Note: Respondents were asked to assume the pandemic would be over by Fall 2021.

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpubeco.2022.104703.

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