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ABSTRACT

Air Pollution Quotas and the Dynamics of Internal Skilled Migration in Chinese Cities*

This paper examines the role of a sulphur dioxide (SO2) emissions quota introduced as part of China's 11th Five-Year Plan on internal movements of high-skilled labour across Chinese prefecture cities. Using data on migration flows calculated through changes in Hukou status, this study suggests that a 1,000 tons increase in the SO2 emissions reduction quota leads on average to approximately a 1.5 percentage points increase in high-skilled net outmigration. Compared to the largest prefectures, this regulation effect is twice as large in the smaller regulated prefectures. A possible mechanism could be that the implementation of SO2 quotas decreases relative labour demand in polluting industries in the regulated cities in the short term, thereby resulting in sectoral transitions from dirty-to-clean industries as well as skilled net outmigration flows. However, this net outmigration trend fades in the long term due to stabilisation in air quality. Our findings help contribute to a broader understanding of the effects of environmental policies on internal labour migration and labour force dynamics.

JEL Classification: J61, O15, Q53, Q58

Keywords: air pollution, China, emissions quota, environmental policy, internal migration, sulphur dioxide

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1 Introduction

Many developed countries in the world today enjoy low levels of air pollution. However, this has not always been the case historically. For example, rapid post-war economic growth resulted in dense smoke haze enveloping many cities and industrial centers around the world. In the UK, this resulted in the Clean Air Act of 1956. In the US, this helped to prompt passage of the 1970 Clean Air Act. China is currently where developed countries were decades ago in terms of the development cycle and starting to face similar environmental consequences. To address this concern, China has introduced several emissions reduction schemes rather than just having a singular focus on transitioning to a first tier economy. Among these schemes, one of the most prominent ones is the Two-Control Zone (TCZ) policy, later revised to become part of a target-based control in the 11^{th} Five-Year Plan (FYP). However, a trade-off for such command-and-control environmental regulation is that it imposes high production costs on polluting sectors, thereby resulting in sectoral labour demand shocks (Greenstone, 2002; Walker, 2013). As a result of these shocks, one can expect that migration-related decisions such as moving to a new city to work and permanent migration are more relevant to skilled labour. This is because high-skilled workers are more likely to be non-agricultural Hukou holders with greater social mobility, and they are likely to have more resources to facilitate making residential changes as compared to low-skilled workers.

Studies on air pollution regulations in the literature highlight that environmental regulations have positive health impacts via a reduction in toxic pollutants. The tradeoff is that it has a negative impact on GDP growth (Chen et al., 2018c; Tanaka, 2015). However, an examination of labour force dynamics resulting from such interventions has not been a focus of previous studies. We posit that environmental stringency *per se* could lead to dynamic mobility of skilled labour due to sectoral employment and ambient air quality changes. Empirical evidence of this dynamic response in developing economies is scant, but important for policymakers who are interested in a separate but related question regarding how a redistribution of the skilled labour force can help address regional development inequality. How do target-based environmental stringency quotas redistribute the high-skilled labour force around China, and to what extent do high-skilled workers respond to stringent environmental regulations?

In this paper, we investigate the role of SO_2 regulation on the dynamics of internal migration of high-skilled labour across 289 Chinese prefecture cities over the period 2000 to 2014.[1] We take advantage of the Two-Control Zone policy and the 11^{th} FYP that provide us a unique opportunity to test our hypothesis. In contrast to recent work by Chen (2019) and Chen et al. (2017) who use five-year periods to capture migration movements, we focus on examining year-to-year variation in skilled labour flows following their exposure to new environmental regulations. Our results suggest that a 1,000 tons increase in the SO_2 reduction quota in a city leads on average to approximately a 1.5 percentage points increase in the high-skilled net outmigration rate during the 11^{th} FYP for 289 prefectures. Compared to the largest prefectures, we find that the effects for smaller regulated prefectures are almost twice as large. This suggests that the high-skilled workforce living in non-mega cities are more likely to migrate. In response to the actual SO_2 emissions reduction at the end of the regulation period, we estimate that the effect of the regulations in terms of migration flows is equivalent to having about 315,000 high-skilled workers migrate out from the smaller regulated cities every year.

The contributions of this paper are threefold. First, this is one of the few studies that directly examines the distributional effects of environmental pollution targets on the high-skilled workforce in a developing economy. Our results provide complementary evidence to the literature that studies local labour market changes due to the 1970 Clean Air Act in the US and the 1987 Air Pollution Prevention and Control Law in China (Chen, 2019;

[1] A prefecture-level city in China is the administrative level between province and county city. Although Beijing, Shanghai, Tianjin and Chongqing are regarded as provinces in terms of the administrative hierarchy, in order to perform a thorough investigation of internal migration patterns in China, we include these four directly-controlled municipalities in our sample. Hereafter, for simplicity, our use of the term "prefecture" in the remainder of this paper includes these four municipalities.

Walker, 2011). Our findings suggest that command-and-control regulations may lead to an unexpected geographic redistribution of skilled labour. Second, we use continuous treatment indicators to reflect varying levels of the mandate that cities were subject to, in addition to the binary treatment indicators more commonly seen in the literature on the TCZ policy. Third, we decompose changes in employment shares due to the new environmental regulations by industry, thereby shedding light on the sectoral distributional effects of environmental regulation on affected skilled workers. Overall, our empirical analysis contributes to a better understanding of the effects of environmental policies on internal labour migration and labour force dynamics on a large scale.

There are several ways in which the SO_2 regulation can affect skilled-labour outmigration. There are four possible channels we can think of. First, skilled workforce outflows in the short term are likely to be due to a reduction in employment in affected industries in regulated prefectures. The target-based regulation imposes an implicit pollution tax on dirty sectors.[2] Affected industries respond to regulatory pressure by reducing employment levels, which represents a direct distributional implication resulting from regulation (Walker, 2011).

Second, a geographic reallocation of polluting firms may redistribute skilled labour. The emission regulations impose high operational costs and negatively impact industrial productivity. A common strategic action for polluting industries involves relocating to less polluted areas (Becker and Henderson, 2000; Shapiro and Walker, 2018). Thus, workers who exhibit a strong linkage with these firms might have an incentive to move.

Third, environmental regulations might contribute to a reduction in income growth. Evidence from the US Clean Air Act Amendments suggest that workers in new plants forgo 20% of pre-regulatory earnings (Walker, 2013). Hence, in a similar fashion, the new stringent environmental regulations in China feature as a labour market demand shock when dirty industries adjust to regulation. Workers who plan to work in polluting

[2]We define the six highest SO_2 emitting industries as a dirty polluting sector, following Chen et al. (2018c)'s definition. Altogether these industries emit 88.17% of total industrial SO_2 in 2005.

industries and who enter the industry after policy implementation will be affected by the new regulations.

Fourth, a decline in skilled net outmigration trends over the longer term could be because of improved air quality due to the SO_2 regulation. Skilled workers living in polluted prefectures face a trade-off between air pollution and prospective career opportunities as polluted air generates a marginal disutility. Hence, an improvement in air quality reduces the disutility of living in regulated prefectures, therefore leading to a decline in outmigration over the longer term.

Our main identification strategy relies on a Difference-in-Difference (DiD) design. In addition to a binary indicator, we utilise a continuous indicator to capture the treatment variation and intensity across prefectures. Chen et al. (2017), Chen (2019) and Rafiq et al. (2017) study internal migration flows either using annual provincial changes or census data that is five years apart. Our paper utilises changes in status in China's unique Hukou system as exogenous variation for 289 prefecture cities from 2000 to 2014, allowing us to focus on year-to-year changes at a much more disaggregated prefecture city level. Moreover, our annual panel data set allows us to examine the short- and long-term dynamics of labour migration flows.

The primary empirical threat to our analysis is that TCZ status and the SO_2 reduction quota is not randomly assigned. In other words, the SO_2 regulations may not be orthogonal to unobserved factors that explain labour migration in our setting. To address this challenge, we control for a set of pre-treatment prefecture meteorological and geographical characteristics. We also perform balancing tests, which help ensure that net outmigration has little association with any concurrent changes in trend patterns due to the SO_2 regulations. We further conduct a battery of sensitivity and falsification tests, involving random assignment of the SO_2 quota stringency and construct three alternative regulation measurements. Together, they reassure us that the estimates we obtain for the effects of environmental regulation are more likely to be casual rather than spurious.

Overall, our findings indicate that human capital mobility can be an unexpected and unintended consequence of environmental regulation aimed at improving air quality. We find that stringent regulation initially leads to skilled outmigration but that the effect fades after 2010, which is the end of the 11^{th} FYP. The remainder of this paper is structured as follows. Section 2 provides a review of the 11^{th} FYP and related literature. Sections 3 and 4 describe the data and identification strategies. Our results and possible mechanisms are discussed in Sections 5 and 6. Robustness checks are presented in Section 7. Finally, section 8 concludes the paper.

2 Related Literature

2.1 Environmental Regulations in the 11^{th} FYP

In 1998, the Chinese central government made its first attempt to control SO_2 emissions and acid rain zones for prefectures exceeding the national emissions standards. However, the effect of the TCZ policy proved to be temporary.[3] The rapid deterioration of air quality has raised much concern and led to a call for more stringent and comprehensive regulations. In August 2006, the government followed up with an evaluation-based pollution control quota for 31 provinces over the period 2006–10 to ensure that the reduction goal was met. The reduction goal assignment for each province was based on an array of economic factors involving pollution intensity, industrial structure and economic factors (Chen et al., 2018d).[4] Each province was subject to a SO_2 reduction quota and their intensities were spatially differentiated across provinces. Provinces with higher economic growth and more vigorous industrial activities such as the Central and Eastern regions were subjected to higher pollution reduction targets (Wu et al., 2017). The central government assigned on average a 9.51% higher quota for TCZ prefectures be-

[3] Shi and Xu (2018) suggest that SO_2 emissions during the 10^{th} FYP after TCZ policy implementation increased by 5.5 million tons, which is nearly a 28% increase from the 2000's emission level.

[4] The details are illustrated in Appendix Table A1.

cause TCZ prefectures are more industrialised, more economically developed and more polluted (Chen et al., 2018c).

To encourage the SO_2 reduction quota under the 11^{th} FYP, province governors were required to sign individual responsibility contracts. The promotion and punishment of individual government officials was linked with local environmental performance in this target-based system. The strong personal career incentives helped to make the overall SO_2 emission allowance well enforced. At the end of the 11^{th} FYP in 2010, the quotas proved to be effective and enforceable. Most of the provinces achieved their targets, and aggregate emissions levels dropped by 14.11% (Shi and Xu, 2018).

However, the downside of air regulation is that it reduces industrial output and increases unemployment. Such employment effects were found following the Clean Air Act of the US in the 1970s. Greenstone (2002) presents evidence that the Clean Air Act caused a reduction in output for counties facing stringent regulations which resulted in approximately 590,000 job losses over 15 years. The Clean Air Act also caused labour in the regulated sectors to experience a 20% pre-regulatory earning loss (Walker, 2013).

2.2 Air Pollution in China

SO_2 is a major air pollutant that harms human respiratory functions (Kermani et al., 2017). It could also convert to PM2.5, which is another main pollutant in China that is detrimental to people's health. Recently, deteriorating air conditions in China have raised public concern in terms of individual health and economic development. Air quality based on SO_2 in China started to worsen since 2003 (Figure 7).[5] Over the course of our study period, SO_2 increased from 14.8 ug/m^3 in 2000 to 27 ug/m^3 in 2014. Our prefecture-level calculations are similar to the 11 ug/m^3 to 23.5 ug/m^3 change reported in Chen et al. (2017)'s county-level calculation over the same period of time.

[5] PM2.5 depicts a very similar trend as that of SO_2, for example, see Chen et al. (2017)'s work. However, as the pollution regulation in the 11^{th} FYP is not directly focused on PM2.5, this paper will focus on SO_2 levels.

Polluted air lowers one's quality of life and increases the likelihood of moving for those who are economically and socially mobile. For example, air pollution increases the infant mortality rate and incidence of respiratory diseases (Arceo et al., 2016; Aunan and Pan, 2004), damages cognitive performance (Zhang et al., 2018), increases mental depression and illnesses (Chen et al., 2018a; Heyes and Zhu, 2019), deteriorates student health and reduces school attendances (Chen et al., 2018b; Liu and Salvo, 2018). Additionally, polluted air causes distortions in labour and firm productivity (Chang et al., 2016; Fu et al., 2018) and the productive output of professional athletes (Archsmith et al., 2018). These examples provided here should be seen as forces that intensify movement from polluted to less polluted cities, not forces that create such movement on their own.[6]

Air pollution control has many implications in policy analysis. The economic cost from air pollution imposes a substantial social burden in China. It is estimated that air pollution imposed a USD 112 billion in welfare costs to the Chinese economy in 2005 (Matus et al., 2012), and Chen et al. (2018a) suggest mental health-related medical costs could proliferate to USD 228 billion if all patients are adequately treated. On the other hand, environmental policy regulation interventions (Huang et al., 2018; Tanaka, 2015) and cleaner fuel substitutes (Cesur et al., 2017) contribute to moderating the deteriorating the trends of air quality.

2.3 Migration Theory

Migration has been documented as an important source of local population composition and regional development (Fan, 2005). Incentives for migration are often based on socio-economic factors. Formally, an older literature in economics considers the drivers of migration as pull and push forces. Push forces include a high unemployment rate and economic underdevelopment at origin. These are forces at the destination that at-

[6] Moving internally rather than internationally (which requires shorter travelling distances and involves little or no restrictions) is a more common reaction to a polluted environment.

tract people. Seminal work by Harris and Todaro (1970) document push-pull forces that suggest that expected employment rates and wages primarily drive migration decisions. Early studies in this internal migration literature primarily focused on rural-urban income differentials. However, various arguments involving income differentials and variability cannot fully explain rural-urban migration as migration still often occurs despite high unemployment rates in urban areas.

Stark and Bloom (1985) view migration as an economic investment for sustained household prosperity. To escape from a potential poverty threat in rural areas, Chinese households often have some family members migrate to high-income areas to find work. This risk diversifying strategy helps households to maintain a higher per capita income (Du et al., 2005; Taylor et al., 2003). Moreover, Fields (1975) argues that social factors might determine job-seeking or migration activities. For example, social networks and better education opportunities in the destination may drive internal migration.

In another branch of migration economics, work by Graves (1980, 1983) emphasises an understanding of amenity-based explanations in shaping the migration process. Amenities refer to an enjoyable local quality of life which includes a mild climate or an abundance of man-made recreational services (Blomquist et al., 1988). Graves's model considers non-economic amenities that compensate for rural-urban wage disparities, and as such, a shift in its demand can induce migration flows. The complementary amenity-based study by Roback (1982) on migration has put a primary focus on developed economies but there has also been increasing attention on migration in developing countries. In the US and Europe, evidence suggests that availability of a vector of natural and man-made amenity options across locations attract immigrants, holding all else equal (Partridge and Rickman, 2003, 2006). In contrast, migrants in developing countries are mainly likely to be driven by economic factors (Lilleør and Van den Broeck, 2011).

To understand the migration process, let us suppose that the central government decides on choosing between stringent or laxed air regulations for each prefecture which contains two types of workers: high and low skilled. Compliance to the command-and-control policy adds an operational cost to local production sectors, thereby causing a higher unemployment rate and a reduction in income. Hence, we further suppose that quota intensity is linear and negatively associated with local income. Each worker type has a probability of moving that is independent of the other. Each individual derives utility from commodity consumption and good air quality and faces the same moving cost, $\bar{C}$. U_i denotes the expected utility for migrating to destination city i, which supplies an attractive climate bundle A, say, better air quality. An individual consumes a composite of commodity X while moving to city i. We further suppose that an economic individual maximises their utility subject to her budget constraint, such that

$$\underset{(X_i, A_i)}{Max} \quad U_i = X_i^a A_i^{1-a}, \;\; subject\ to \;\; I_i \geq X_i + P_A A_i.$$

I_i is a real budget for each individual. The price of a commodity is normalised to 1 for simplicity. P_A is the price that an individual is willing to pay for air quality; some attractive cities with better air quality in China may have lower expected income or fewer job opportunities. The indirect utility $V_i(I_i, P_A)$ is obtained from solving the above unconstrained maximisation. In analogy, the indirect utility for currently residing in city 0 is denoted $V_0(I_0, P_0)$. Therefore, migration towards city i occurs if $V_i(I_i, P_A) > V_0(I_0, P_0)$. When $V_i(I_i, P_A) = V_0(I_0, P_0)$, an individual is indifferent between migrating and staying. Often, people in the megacities in China are less likely to emigrate due to the benefit provided by these cities. The future career opportunities and high-quality schools in these cities compensate for the disutility of heavy traffic and polluted air. However, air quality is playing an increasingly important role in skilled labour mobility.

3 Data and Variables Construction

3.1 Net Outmigration Rate

In the Chinese context, under the Hukou registration scheme, each Chinese citizen is classified as being part of either the agricultural or non-agricultural population. The agricultural Hukou was designed to restrict rural-urban population flows and to support agricultural production in the 1960s (Young, 2013). Agricultural and non-agricultural Hukous are associated with different social welfare benefits. Agricultural Hukou holders are at a disadvantage as they are not entitled to the same urban health insurance and employment subsidies as non-agricultural citizens are. Hukou inequality is discriminatory in education because children with an agricultural Hukou have limited access to the elite urban public schools. For example, these schools located in urban areas require extra payments or prohibit enrolment to those with agricultural Hukous. By comparison, an urban non-agricultural Hukou ensures complete access to neighbourhood public schools and medical insurance.

Moreover, in Chinese cities, urban jobs or white-collar professions are dominated by non-agricultural Hukou holders (Guo and Iredale, 2004). Fu and Ren (2010)'s descriptive analysis using the 2005 Chinese micro-census data shows that non-agricultural Hukou holders received on average around 12 years of education, which was 3.7 years higher than agricultural Hukou holders. Additionally, more than 70% of the non-agricultural population were in white-collar jobs such as clerical, leadership and professional services. At the same time, less than 20% of agricultural Hukou holders were in these professions. In addition, non-agricultural Hukou holders earned more than twice as much as agricultural Hukou holders. A logical conjecture is that the better educated group has access to better resources and a higher ability to move.

Our work is able to trace the movement of high-skilled workers using the fact that relocating Hukou in China requires certain conditions to be met, such as having a stable income and occupation or owning a house or property in the destination.[7] Therefore, urban areas are heavily populated by high-skilled workers and these workers are also more likely to be non-agricultural Hukou holders. In essence, we argue that non-agricultural Hukou holders at urban districts are a good proxy for high-skilled workers while agricultural Hukou holders could measure the size of the low-skilled labour force. We confirm such a conjecture by plotting the correlation between the two types of Hukou with educational attainment in the 2010 population census across 289 prefectures cities. Figure 3 shows that urban non-agricultural Hukou depicts strong correlations with higher educational attainment, while having an agricultural Hukou is tightly correlated with lower educational degrees (e.g. middle school and below). Moreover, we find a little correlation between agricultural Hukou and higher education (for example, bachelors and masters degrees).

In light of the above analysis, our definition of approximating high-skilled permanent internal migrants using urban non-agricultural Hukou holders is justified. This definition also aligns with two earlier studies that document that highly-educated people (urban non-agricultural Hukou in our context) are more likely to be permanent migrants (Carrington and Detragiache, 1998; Docquier and Marfouk, 2004).

To model net migration flows, we adopt a residual approach (Beine and Coulombe, 2018; Chen et al., 2017; Feng et al., 2010; Passel et al., 2004) to capture the net out-migration rate for city c at year t as

$$Net\_Migration\%_{c,t} = \frac{NonAgr_{c,t-1} - NonAgr_{c,t}}{NonAgr_{c,t-1}} - Natural\ Pop.\ Growth\%_{c,t}. \tag{1}$$

In Equation 1, the first term shows the net change in urban non-agricultural Hukou holders. The second term is the natural population growth rate for the respective urban district. Positive $Net\_Migration\%_{c,t}$ values indicate net outward migration from a city

[7] Explanations can be seen at State Council's official website: http://www.gov.cn/xinwen/2014-07/30/content_2727331.htm.

while a negative value represents net inward migration. To enrich our analysis, we apply the same formula and define two additional annual migration flows: total and low-skilled outmigration rates. Total net outmigration is calculated through total Hukou change. Low-skilled labour is calculated through a change of total rural Hukou (total Hukou minus total urban Hukou).[8] Population data is from the Chinese City Statistical Yearbook 1999-2009, supplemented by data from the Demographic Statistical Year Book 2010-2016.[9]

Compared with other internal migration calculation methods in the literature, our approach has several notable differences. First, our calculation adjusts for population growth rates and differentiates between high- and low-skilled labour. This is in contrast to Rafiq et al. (2017)'s study which calculates yearly aggregate temporary migrants at the provincial level.[10] Second, we focus on annual linkage over a longer time period that extends what is examined in Chen et al. (2017) and Qin and Liao (2016) who calculate an inter-county outmigration rate using cross-sectional censuses over five-year periods until 2010. Third, we consider administrative division changes that confound migration rate calculations. For example, a prefecture, Chaohu, was split in 2011 and three neighbouring prefectures absorbed its population. Therefore, the change of statistical accounting creates threats to our identification. Around 7% of prefecture cities and 12% of their urban

[8]China National Bureau of Statistics stopped disclosing the number of rural non-agricultural Hukou holders from 2009. Due to data limitations, low-skilled labour comprises of both rural agricultural and rural non-agricultural Hukou holders. However, our calculation based on the available 2000-2008 data shows on average that only 19.8% of non-agricultural Hukou holders live in a rural area. Further, people in rural areas have lower chances to work in a high-wage job. It is reasonable to assume that results for this group are not primarily driven by the small proportion of rural non-agricultural Hukou holders. Nevertheless, we will not focus on interpreting casual effects for low-skilled workers but merely regard it as qualitative counterpart for high-skilled ones.

[9]We did not use county-level data because such data do not distinguish between urban and rural categories or report numbers of non-agricultural Hukou. Furthermore, the sample period stops in 2014 because the State Council formally abolished the designation of agriculture and non-agriculture Hukous in 2014. See for `http://www.gov.cn/zhengce/content/2014-07/30/content_8944.htm`.

[10]In general, caution must be applied to the degree of reliability of results that are based on provincial data. This is because intra-provincial migration flows constitute a large proportion of overall migration since 1990 (Liang and Ma, 2004). As ignoring the intra-provincial movement is questionable for a comprehensive evaluation of internal migration flow in China, our paper sheds more light on such internal migration flow patterns by being based on prefecture city level data.

districts experience administrative splits or merges between 2000 to 2014. For these cases, we drop prefectures in the year when they experience an administrative division and combination.

Net outmigration rates can have both positive and negative values, and inward migration flows do not need to equal outward migration flows for China as a whole. The distribution of the total net outmigration rate depicted in Figure 2 and descriptive statistics presented in Table 1 suggest mean negative values, which is qualitatively consistent with Chen et al. (2017)'s calculation using census data. This means that the 289 prefectures in the course of our study have predominately experienced inward flows. This is especially the case for China's Tier one cities, such as Beijing, Guangzhou, Shenzhen and Shanghai, where the development policy was to target and attract talented people with prospective urban career opportunities.

The histogram and descriptive statistics also reveal that permanent migration flows for high-skilled labour (involving Hukou Change) is much higher than it is for low-skilled labour. This suggests that the high-skilled workforce is the group that is responsible for the major source of migration flows. It is also consistent with the fact that high-skilled workers have more resources and abilities to do so. Further, as shown in Figure 4, low-skilled labour flows are similarly trended in both the TCZ and non-TCZ prefectures throughout the period. In contrast, high-skilled labour in the TCZ prefectures, relative to non-TCZ prefectures, are more likely start to migrate outwards between 2006 and 2007. However, we observe a decline in high-skilled outmigration at the end of 11th FYP (2010), and the overall outmigration trend fades after 2012.[11]

[11] We found similar trends when using the mean value of our continuous treatment indicator to split the sample.

3.2 Meteorological and Prefecture-level Variables

The daily weather data, including temperature, cumulative precipitation, sunshine duration, relative humidity and wind speed comes from the China Meteorological Data Sharing Service System (http://data.cma.cn/). We successfully merged 252 out of an overall 839 weather stations to its nearest prefecture. SO_2 mass concentration data comes from monthly data provided by NASA. Specifically, we use the Modern-Era Retrospective Analysis for Research and Application Version 2 (MERRA-2), which has a spatial resolution of 0.5 $\times$0.625 degrees (45 KM $\times$ 55 KM). We collapsed the data by year to calculate annual averages of weather variables and SO_2 concentration levels.

An abundant literature documents that a better climate is one of the essential factors that contribute to local population growth, and this is particularly attractive to a new generation of high-skilled workers seeking work-life balance. As such, we collect a list of variables on amenities from the City Statistical Yearbook which provides information such as the number of doctor and hospitals, green coverage rate, and paved roads (reported in Table A3).

Our complete panel prefecture data set includes a list of migration variables, prefecture characteristics, emission quotas, and geographical and meteorological variables for 289 prefectures over the period 2000 to 2014.

4 Identification

4.1 Baseline Specification

This study investigates the effect of TCZ status adoption across prefectures, as well as the effect of SO_2 regulation intensity as measured by emissions quotas weighted by prefecture production activity, on internal skilled outmigration rates. The ideal research setting for TCZ status is for it to be assigned randomly. In the absence of randomisation, we take advantage of our panel data that covers a long period of time which allows us to capture trends in rapid internal migration growth before and after the introduction of environmental regulations for some prefecture cities. Such spatial-temporal variation in exposure to a treatment allows for the use of a Difference-in-Difference (DiD) estimator. This study begins with the following baseline model:

$$y_{c,t} = \beta_1(TCZ_c \times Post_t) + \mathbf{X_{ct}}\beta_2 + \mathbf{Z_c} \times \mathbf{f(t)} + \delta_c + \lambda_t + \epsilon_{c,t}. \tag{2}$$

$y_{c,t}$ is a vector of net outmigration rates at prefecture c in year t that contain total, low-skilled and high-skilled net migration rates. $Post_t$ equals 1 after 2006 and is 0 otherwise. $TCZ_c \times Post_t$ is a binary indicator that equals 1 if prefecture c is part of the TCZ treatment in a post treatment period t. β_1 is the coefficient of interest and represents any permanent relocation of skilled workforce associated with the adoption of TCZ status. $\mathbf{X_{ct}}$ is a set of push-pull determinants that capture variation in amenities and urbanisation which help explain net outmigration rates, such as green coverage rate and local education supply (indicated in Table A3). $\mathbf{Z_c}$ is a vector of TCZ selection variables to control for omitted variable bias. However, the TCZ variables that help explain the migration rate, such as SO_2 concentration, could be affected by TCZ status, which in turn will bias the DiD estimator. To address this issue, we project counterfactual trends for initial TCZ conditions in the absence of TCZ status (Chen et al., 2018c). The projection is done using TCZ selection variables averaged over 1990 to 1995 (prior to TCZ designation) interacted with a flexible third-order polynomial of time trends, which is $\mathbf{Z_c} \times \mathbf{f(t)}$ indicated in above equation. Our results using fourth- and fifth-order polynomials in the later section remain robust and hardly change, suggesting that the third-order polynomials properly capture variation in the counterfactual trends.

δ_c is a set of prefecture fixed effects that account for unobserved time-invariant permanent differences across prefectures. One might be concerned that there exist staggered adoption times of the Provincial Talents Policies for attracting high-skilled workers, which could lead to skilled immigration and result in biasing estimates of the SO_2 regulation effects on migration flows. We investigate such a concern by including a set of province-by-year fixed effects which help capture unobserved dynamic province-specific shocks to migration and neighbouring spillovers common to prefectures within a province. However, the downside is that including these fixed effects will result in dropping Beijing, Shanghai, Chongqing and Tianjin as they are coded as provinces. When we exclude these four municipalities, our findings are robust to an inclusion of these interactive fixed effects, suggesting that the Talent Campaigns across different provinces cannot account for our findings.[12] Finally, $\epsilon_{c,t}$ is the error term. Standard errors are clustered by prefecture to allow for heteroscedasticity and correlation within prefectures over time.

4.2 Air Pollution Reduction Quotas

A binary TCZ dummy depicts a clear picture of the distribution of SO_2 regulation in China. However, a binary TCZ variable cannot fully capture the continuous nature of treatment intensity in a DiD setting. In practice, non-TCZ prefectures are not equivalent to prefectures receiving zero treatment; rather, it reflects a lower dosage of treatment (Tanaka, 2015). Therefore, in order to account for the effect of different levels of regulation intensity on net outmigration rates, we replace the binary TCZ dummy with a continuous treatment variable in Equation 4 and estimate the following:

$$y_{c,t} = \beta_1(Quota_c \times Post_t) + \mathbf{X_{ct}}\beta_2 + \mathbf{Z_c} \times \mathbf{f(t)} + \delta_c + \lambda_t + \epsilon_{c,t}, \tag{3}$$

where $Quota_c$ is the SO_2 emission reduction per million tons in prefecture c during the 11th FYP. We follow Chen et al. (2018d)'s quota estimation method and partition the pro-

[12]Due to the space constraints, these results with province-by-year fixed effects that controls for time-varying provincial policies are available upon request.

vincial quota to the prefecture level, using as a weight the production activity of each SO_2 emitting industry in 2005 relative to its provincial output. Formally,

$$Quota_c = \Delta Quota_{p,05-10} \cdot \sum_{i=1}^{39} \mu_i \frac{output\ value\ of\ industry\ i\ in\ city\ c}{output\ value\ of\ industry\ i\ in\ Province\ p}. \quad (4)$$

The first term, $Quota_{p,05-10}$ is the absolute change of the mandated SO_2 emission reduction during the 11^{th} FYP. μ is the industrial weight for each industry in the SO_2 polluting industry (see Appendix Table A2). The third fraction is the proportion of industrial output weight of each industry in each prefecture over its aggregate provincial output, calculated using the 2005 annual survey of Chinese industrial manufacturing firms (ASIF) data set.[13] The means and standard deviations for quota intensity are presented in Table 1, which reveals that the TCZ prefectures were assigned stricter emissions quota levels. This is the case irrespective of whether we use alternative ways to compute the quotas.

4.3 Identification Threats

Pre-existing differences in prefecture characteristics is a potential threat to the parallel trend assumption in the pre-treatment period. TCZ prefectures are more polluted and industrial-oriented, while non-TCZ prefectures are largely comprised of an agricultural sector and are less polluted. The sectoral employment in Table 1 shows, for example, that the employment share of manufacturing (secondary industry) is higher in the TCZ prefectures, while non-TCZ prefectures have a much larger agricultural employment share (primary industry). The urban tertiary employment (service sector) share is similar across the TCZ and non-TCZ prefectures. We observe that citizens are richer and more educated in regulated prefectures before treatment. Balancing test results in column (5) of Table A3 indicate that there are significant differences in the means for many characteristics. How-

[13] ASIF is the most comprehensive Chinese firm-level survey which is widely used by many scholars (Brandt et al., 2012; Chen et al., 2018d; Lu et al., 2010). All above-scale firms (Annual revenue above 5 million CNY before 2012 and 20 million CNY after 2011) are required to disclose their financial and accounting information to NBS each year.

ever, once we control for the TCZ selection variables, such as pre-TCZ SO_2 concentration and associated weather conditions, column (6) shows that differences become either statistically insignificant or economically indistinguishable from zero. Therefore, this balancing exercise helps improve the pre-policy matching of trends between the treated and control groups.

A second threat to the DiD design is that the prefecture characteristics that explain outmigration rates are likely to be affected by TCZ status in the treatment period. That is, the treated and control groups are not similarly trended in the absence of treatment, thereby confounding the DiD estimator. We therefore repeat the first balancing exercise but estimate the baseline specification over a longer period. Columns (7) and (8) of Table A3 present little evidence for systematic differences in trend patterns after the policy change, once we control for TCZ selection, and include province-year and prefecture fixed effects. Our observable prefecture characteristics, initial conditions and fixed effects should have helped capture considerable variation in the error term. This suggests that the remaining variation in TCZ status should be orthogonal to the trends of unobserved factors that explain net migration rates. We therefore have confidence in the credibility of our DiD design. We next proceed to investigate the effects of TCZ regulation on internal migration rates.

5 Empirical Results

5.1 Baseline Results

We begin by presenting the estimates of the impact of the binary TCZ treatment variable on three categories of net outmigration rates, as well as estimates based on the continuous treatment intensity variable, $Quota_{c,05-10}$. The results are reported in Table 2. Columns (1) to (5) present estimates by including fixed effects, pre-treated TCZ selection variables interacted with third-order polynomial time trends, and prefecture controls. At first glance, these results suggest that the estimated coefficients are much larger in the high-skilled category, although statistical significance fades after controlling for fixed effects and additional controls in columns (4) and (5). However, it is unlikely that the binary TCZ status variable paints a full picture of spatial variation in the policy reforms. This is because non-TCZ prefectures are still treated, only with a lower dosage.[14]

To account for the treatment intensity, we replace the binary TCZ indicator with a continuous quota measurement. Columns (6) - (9) of Panel A of Table 2 shows that environmental regulation results in outmigration from stringently regulated prefectures during the 11^{th} FYP. We next search for whether this effect varies by different types of skills in Panels B and C. According to the coefficients reported in column (9), high-skilled workers are responsive to environmental regulations in contrast to no migration effects for low-skilled labour during the 11^{th} FYP. However, we do not find a significant outmigration effect when using the extended sample period 2000-2014 in column (10), which implies that the outmigration trend may have faded after the end of the 11^{th} FYP.

These results are consistent with our hypothesis that high-skilled workers are inclined to move when they encounter socioeconomic changes because they are more likely to have resources and the ability to migrate if necessary. High-skilled workers will likely seek work in better areas if their wage or career prospects are negatively impacted by the SO_2 quota. The positive point estimates in column (9) suggest that a 1,000 tons reduction in SO_2 emissions leads to a 0.73 percentage points change in the total net outmigration rate and a 1.5 percentage points change in the high-skilled net outmigration rate.[15]

[14] Tanaka (2015) points out that a binary TCZ status may not fully reflect true variation in SO_2 regulation intensity. However, due to data limitations at the time of his study, he did not utilise a continuous treatment variable in his DiD design.

[15] While urban-to-rural hukou conversion is under strict control due to the protection of agricultural land in rural areas, restrictions on rural-to-urban Hukou conversion have been increasingly relaxed. Despite the higher provision of public goods in urban areas, rural Hukou holders have few incentives to transition to an urban Hukou because they will lose their income from their rural land, face inflated living costs in the urban area, and be unlikely to find a skilled urban job (Chen and Fan, 2016). For these reasons, local Hukou conversion is unlikely to account for much prefecture outmigration.

5.2 Top 10 vs Non-Top 10 Cities

Although our prefecture-specific model provides evidence that stringent SO_2 regulation causes higher outmigration out of a regulated prefecture, it is possible that Hukou holders living in mega cities may be unlikely to permanently outmigrate due to access to high quality local education and first-rate medical resources. Therefore, this possibility leads us to investigate whether the outmigration effects are driven by non-mega cities. To do so, we introduce a dummy for the 10 most populated cities in China and estimate the following specification:

$$y_{c,t} = \beta_1(Quota_c \times Post_t \times Non\_Top10_c) + \mathbf{X_{ct}}\beta_2 + \mathbf{Z_c} \times \mathbf{f(t)} + \delta_c + \lambda_t + \epsilon_{c,t}, \qquad (5)$$

where Non_Top10_c is a dummy variable that is set to one for a prefecture which does not belong to the 10 most populated cities (we also create a $Top10_c$ dummy for cities that belong to the top 10 city list to facilitate discussion).[16] The results are presented in Table 3. We find that low-skilled workers are still unresponsive to environmental regulations in both top 10 and non-top 10 cities. By comparison, the effects for high-skilled workers in non-top 10 cities are economically significant at the 1% level. At the same time, we find much smaller and insignificant effects for skilled net outmigration in the top 10 cities. Combined, these results suggest that environmental regulations more likely result in spatial sorting for high-skilled labour in non-mega cities because the value of holding on to Hukous from non-mega cities is not a binding constraint. However, people in mega cities are much less responsive to environmental regulations and reluctant to make permanent Hukou changes. The trade-off for them to permanently outmigrate from a top 10 city to a non-top 10 city is to abandon their very valuable and hard to obtain Hukou for a mega city.

[16] The top 10 cities include Beijing, Shanghai, Tianjin, Chongqing, Chengdu, Shenyang, Guangzhou, Dongguan, Shenzhen, Wuhan. Listed cities are economically advanced and this list has remained stable over the years.

We find that the regulation effect is almost twice as large in non-top 10 cities. The result in column (7) shows that an average increase in the SO2 quota by 1,000 tons leads to an average increase in high-skilled outmigration rates in the non-top 10 cities by 0.029 percentage points. At the mean level of the quota (0.84), the average treatment effect of the policy on outmigration rate of high-skilled workers is 0.24 percentage points (0.29*0.84) in non-mega TCZ cities. Therefore, using the quota specification, the effect in terms of the average annual high-skilled net outmigration rate is 9.2% (0.24/2.62). On average 3.42 million urban non-agricultural Hukou holders made their Hukou status change (netting out natural population growth) every year during the treatment period. Therefore, the effect of the regulations in terms of migration flows is equivalent to having about 315,000 high skilled workers migrate out from the smaller regulated cities annually.[17]

5.3 Stages of Regulation Effects and Pre-existing Trends

Having established the effect of the SO_2 regulation on skilled outmigration, we next focus on tracing the effects of the policy by year using an event-study approach. We modify Equation 2 by replacing $post_t$ with year dummies. The dynamics of internal migration can be disentangled into three parts, which is given by

$$y_{c,t} = \underbrace{\sum_{j=2000}^{2004} \beta_j \times TCZ_c \times Year_j \times Non\_Top10_c}_{\text{Before Effect}} + \underbrace{\sum_{j=2006}^{2010} \beta_j \times TCZ_c \times Year_j \times Non\_Top10_c}_{\text{Short-term Effect}}$$
$$\underbrace{\sum_{j=2011}^{2014} \beta_j \times TCZ_c \times Year_j \times Non\_Top10_c}_{\text{Long-term Effect}}$$
$$+ \mathbf{X_{ct}}\beta_2 + \mathbf{Z_c} \times \mathbf{f(t)} + \delta_c + \lambda_t + \epsilon_{c,t}. \quad (6)$$

[17]For TCZ cities, the average treatment effect of the policy on outmigration rate of high-skilled workers is 0.519 in non-mega TCZ cities. The effect in terms of the average annual high-skilled net outmigration rate is 19.8% (0.519/2.62), which suggests that the 11^{th} FYP has an effect equivalent to about 684,000 high-skilled outmigrants (3,420,000*0.2) each year using the binary specification.

$Year_j$ is a year dummy which takes on a value of 1 if year equals to j. Since the treatment date is between 2006 and 2007, we use 2005 as the reference category. The *Before-Effect* period assesses the validity of our research design by examining whether there are any pre-existing trends that drive our findings. As a visual demonstration, Figure 5 plots the coefficient for the three outcome variables along with a 95% confidence interval. The estimates for the pre-treatment period between 2000 and 2004 are insignificant and stable, suggesting that there is no evidence of systematic changes in migration trends for TCZ prefectures prior to the 11^{th} FYP conditional on a set of fixed effects and controls. Therefore, it is unlikely that our results are a reflection of efforts made before the policy reform.

The *Short-term Effect* period documents the stage of each regulation effect during the 11^{th} FYP and the *Long-term Effect* window seizes any possible reduced impact over the post-period 2011 to 2014. In Figure 5 (top panel), we find some evidence of a distributional effect of the environmental regulation on aggregate net outmigration rates for non-top 10 TCZ cities. We next examine heterogeneity by high-skilled and low-skilled workers. In Figure 5 (middle panel), the estimates are positive and increasing in magnitude till 2010 (the end of the 11^{th} FYP) for high-skilled workers, while the regulation effects gradually diminish a few years after the 11^{th} FYP.[18]

In contrast, low-skilled labour is less responsive to changes in the environmental regulations illustrated in Figure 5 (bottom panel). However, there appears to be an effect of inward migration in 2014, the year when the central government started Hukou reform and subsidised rural-to-urban Hukou transformation.[19] This result is consistent with rural Hukou holders having an incentive to migrate to urban non-mega TCZ prefectures at the beginning of the Hukou reform period in 2014 (Chen and Fan, 2016). Overall, Figure 5 suggests that environmental regulations can redistribute high-skilled labour in the short term, but this effect is likely to fade over the long term. The short-term out-

[18]The diminishing long-term regulation effect after 2010 corresponds to Table 2 and 3 that the effect is smaller when incorporating an extra four years of data after the the 11^{th} FYP.

[19]`http://www.gov.cn/zhengce/content/2014-07/30/content_8944.htm`

migration effect is possibly caused by a decline in demand for employment in certain sectors and complements the findings documented by Chen et al. (2018c) that reducing SO_2 industrial emissions can be costly and is at the expense of local GDP growth.

So far, we have established the evidence for an effect of the environmental regulation on the high-skilled workforce. However, the direction of movement, which may interest policy-makers, remains unclear due to the nature of net outmigration rates. We discuss the possible destinations for high-skilled labour in the next subsection.

5.4 Direction of Internal Migration Movement

In the past few decades, the Eastern provinces have experienced a net inflow of high-skilled labour as the flourishing local economic conditions offer prosperous career opportunities and represent target destinations for many graduates. However, an emerging trend is that high-skilled workers have started to factor in air pollution in their utility functions which affect their outmigration decisions (Chen et al., 2017; Khanna et al., 2019). A recent survey focusing on Beijing, a city with many exceptionally talented and skilled workers, finds that since 2011, severe air pollution has decreased the willingness of young college graduates to work in this city (Hao et al., 2020). Instead, possible alternative choices for the young graduates are to relocate to second- or third-tier prefectures in their quest for higher amenities and work-life balance. This results in an increased internal flow of migrants to the less economically advanced cities.

Surprisingly enough, recent studies by Gu et al. (2019) and Khanna et al. (2019) based on the 2015 Population Census suggest a new pattern of internal migration flows in contrast to traditional Central-to-East migration movement. Increasing in-migration and decreasing outmigration trends were seen after 2010 in traditional Central migration donor provinces for the first time since 1995 (Zhou et al., 2018). This reverse flow involves high skill workers outmigrating from the wealthy but polluted Eastern provinces. Thanks to the improved air quality since 2010, the Central and Western provinces have recently become more viable places for high-skilled workers to move to.[20] Zhou et al. (2018) confirms this finding by showing that a considerable number of candidates admitted to the most competitive national academic programs choose to move to the Central and Western areas, although it is still the case that Eastern provinces continue to attract most of the country's top scholars.

Such population outflows away from Eastern provinces can be the result of new initiatives by the government, including "The Rise of Central China, The Western Development and Talents Attraction" policies. These campaign activities focus on attracting talent to the second- and third-tier prefectures and promote desirable lifestyles for a high-skilled workforce. Hence, along with gradually evolving economic developments in Central and Western China, internal migration movements towards these provinces is projected to continue in 2016–2030 if the differentials regarding local amenities and economic opportunities between tier-one and other cities continue to diminish (The Economist Intelligence Unit, 2018).

Throughout the analysis, our results have documented that the 11^{th} FYP environmental regulation from 2006 has led to an increase in outmigration, with the effect found to be stronger for the skilled workforce. In the next section, we investigate possible mechanisms through which the SO_2 regulation reshapes the sectoral distribution of labour in the short- and long-term.

[20] Air pollution differences across cities can lead to a spatial sorting on skills. According to Figure 3 of Khanna et al. (2019), many Central and few Western provinces (such as Sichuan) can be attractive for high-skilled workers to reside in. On the other hand, low-skilled workers are less sensitive to air pollution and are more evenly geographically distributed across China.

6 Mechanisms

6.1 Relative Labour Demand Change

To achieve the SO_2 reduction target, local government officials shut down manufacturing plants and required them to install new desulphurisation technologies. As new stringent environmental policies on SO_2 emissions reductions impose a high cost in highly regulated prefectures, the immediate effect is to lower output and real GDP growth. The associated consequence is likely to be higher unemployment which will cause an increase in the outmigration rate. A similar case is the Clean Air Act in the US which was implemented thirty years ago, where it was found that air pollution regulations led to a reduction in income and substantial job losses (Greenstone, 2002; Walker, 2013). Hence, we also expect that new environmental regulations should lead to lower labour demand in China.

To study employment effects, we use ASIF data from 2000 to 2013 and evaluate the effect of SO_2 regulation on polluting and non-polluting industries. As the China NBS only surveys industrial firms with an annual revenue above 5 million Chinese Yen (CNY), with the above-scale survey standard modified to 20 million in 2011, this makes a comparison of the industrial employment statistics over time impossible. Moreover, the 5 million CNY survey cutoff used before 2011 is also an issue as due to monetary inflation, the cutoff is not comparable across years. To mitigate such sampling concerns, we explore the sectoral employment change in the ASIF data and propose two different relative labour demand variables:[21]

$$EmpShare\_Province_{i,c,t} = \frac{\sum Employment\ at\ industry\ i\ in\ city\ c\ in\ year\ t}{\sum Employment\ in\ Province\ p\ in\ year\ t}, \tag{7}$$

[21] Our results are similar when changing the denominator to $\sum Employment_{i,p,t}$ or $\sum Employment_{i,t}$. We do not use $\sum Employment_{i,c,t}$ as the denominator because manufacturing industries are unequally geographically distributed in China. In particular, many prefectures in the Western provinces have very few manufacturing industries due to poor economic conditions. As such, employment for manufacturing firms in these cities barely experience any changes. Hence, using such a denominator will not fully capture year-by-year variation in relative labour demand.

$$EmpShare\_Total_{i,c,t} = \frac{\sum Employment\ at\ industry\ i\ in\ city\ c\ in\ year\ t}{Total\ Employment\ in\ year\ t}. \quad (8)$$

We begin by examining the degree to which changes in the SO_2 regulations have led to relative labour demand changes in the years following the introduction of the policy for all polluting industries. We estimate the baseline specification in Equation 2 and the result is shown in panel A of Table 4. We find that on average the SO_2 regulation decreases the relative demand for labour in these industries as expected. Interestingly in Panel B, the results suggest little evidence that regulation has led to a relative reallocation of labour away from the electricity supply industry during the 11^{th} FYP. Such unresponsiveness to the environmental regulations could be the case for the energy industry because over the 14 years in our study period, China's national GDP was growing at an average rate of 7% annually. Consequently, the demand for industrial electricity has surged. For example, China's electricity consumption was 1/3 of that in US in 2000, but was 1.2 times higher than the US in 2013.[22] Moreover, the energy industry is mainly state-owned and has served as the backbone for rapid-growing manufacturing activities in China. As a result, a possible coping strategy in the energy industry could be installations of desulphurisation (scrubbers) technologies rather than cutting down on employment.

Since the effect is not salient for the electricity supply industry, we further explore other polluting industries. These include non-metal mineral, ferrous metal smelting and pressing, and chemical products. Compared to the energy industry where employment changes were minimal, the DiD estimates in Panel C-E of Table 6 reveal that regulations decreased relative labour demand in these polluting industries for both the periods 2000-2010 and 2000-2013. This result is not sensitive to using an alternative construction of the outcome variable.[23]

However, our results for the top six polluting industries might be confounded by

[22] https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html
[23] ASIF data is only available until 2013.

prefecture-specific time-varying unobserved variables common to both the SO_2 regulation and the outcome variable (e.g. time-varying prefecture-by-industry policies). To gauge the net impact on the SO_2 polluting industry, we identify regulation effects using a Difference-Difference-Difference (DDD) specification

$$Dirty\_EmpShare\_Province_{i,c,t} = \beta_1(TCZ_c \times Post_t \times Dirty_i) + \delta_{ct} + \gamma_{ic} + \lambda_{it} + \epsilon_{i,c,t}, \quad (9)$$

where $Dirty_i$ is 1 if an industry belongs to the top six SO_2 polluting industries. $\delta_{it}, \gamma_{ct}, \lambda_{ic}$ are two-way industry-year, prefecture-year and prefecture-industry fixed effects respectively. The results are presented in Panel A of Table 5. The results suggest that our main findings from our DiD model (that relative labour demand in SO_2 emitting industries decreases) still holds. The estimates are similar to those in Panel A of Table 4, implying that our DiD estimator for industry analysis are unlikely largely biased by time-varying unobservables.

One may wonder what role the energy supply industry, the major industrial SO_2 emitter, plays in a DDD setting. We reconstruct two employment variables by excluding the energy industry and re-estimate Equation 9. If the energy industry responds to regulation and cuts jobs, we should observe a reduction in the magnitude of our estimates. The inflated estimates in Panel B of Table 5 suggests a robust result that the energy supply industry does not reduce relative labour demand even under the pressure of new SO_2 emissions quotas.

6.1.1 Sectoral Transition for the High-skilled Workforce

As we have established the negative impact of air regulation on relative labour demand in the polluting sector, we next look at some possible internal redistribution of the high-skilled labour force from the polluting sector to other skilled sectors. We collect a list of skilled occupations from the China City Statistical Yearbook. The broad categories include finance, computer software, health, public administration and environmental management. We follow Equation 7 to construct the relative labour demand for these skilled occupations from 2003 to 2014.[24]

To visualise the yearly changes of the environmental regulation effects, we regress the employment share of five high-skilled categories in an event study framework as follows.

$$Skill\_EmpShare\_Province_{c,t} = \sum_{j=2003}^{2013} \beta_j (TCZ_c \times Year_j) + \mathbf{X_{ct}}\beta_2 + \mathbf{Z_c} \times \mathbf{f(t)} + \delta_c + \lambda_t + \epsilon_{c,t}.$$

We then plot year-to-year marginal effects across the various skilled occupations, complemented by year-to-year marginal effects for the SO_2 dirty sector.[25]

Figure 6A shows that relative labour demand decreases one year following the regulation in the regulated dirty sector. Interestingly, the effect becomes nearly zero in 2010 (the last year of the 11^{th} FYP). In that year, industrial employment performance was also evaluated by Chinese State Councils and linked with prospective promotions or punishments. Furthermore, we observe a sustaining decline in the effects of SO_2 regulation on relative labour demand after 2010. In a sharp contrast, we find opposite trends for relative labour demand in some other skilled occupations: finance, health, computer and public sectors (Panel B-F). This suggests a possible dirty-to-clean industry job transition for the high-skilled workforce as a result of the tigher SO_2 regulations in the polluting sectors in TCZ prefectures.

Our results correspond to a job-to-job transition when an environmental regulation takes place in a general equilibrium framework, as highlighted in Hafstead and Willi-

[24]The China NBS used different accounting standards before 2003 so we are unable to use data prior to 2003..

[25]We estimate the following specifications for dirty sector,

$$Dirty\_EmpShare\_Province_{i,c,t} = \sum_{j=2000}^{2013} \beta_j (TCZ_c \times Year_j \times Dirty_i) + \delta_{ct} + \gamma_{ic} + \lambda_{it} + \epsilon_{i,c,t}.$$

ams III (2018)'s study. It is possible for environmental regulations to have little aggregate impact on unemployment in China as a whole; however, sectoral employment transitions among prefectures can still occur when a dirty sector is regulated and its production cost increases correspondingly. Therefore, a likely consequence is that labour from the regulated dirty sectors in the regulated prefecture outmigrate to a clean sector and to some clean jobs at more leniently regulated prefectures. In particular, urban Hukou holders in mega cities would be more likely to consider within-prefecture job transitions than abandoning their valuable mega Hukou.

6.2 Non-deteriorating SO_2 Concentration

The second mechanism related to internal migration is the change in air pollution concentration. Recent studies by Chen et al. (2017) and Qin and Zhu (2018) suggest that air pollution either drives internal migration or spurs people's migration interests. Among the literature discussed, Chen et al. (2017) is arguably the first study looking at the causal impact of air pollution on internal migration flows in China counties. Their analysis shows that air pollution has increased the net outmigration rate of total migrants (both temporary and permanent). They conclude that air pollution leads to marginal disutilities and that well-educated young adults at the beginning of their career are the main drivers of such a flow.

We document this pattern in Figure 7. It shows that the TCZ prefectures are more polluted.[26] The projected SO_2 concentration premium between the TCZ and non-TCZ prefectures is expected to be higher if there had been no regulatory intervention on SO_2 levels. It is noticeable that after 2008, the pollution difference between TCZ and non-TCZ cities remains constant. This implies that air quality is not deteriorating further in the TCZ prefectures relative to non-TCZ prefectures, and could explain why high-skilled

[26] The time trend for PM2.5 levels can be found in Chen et al. (2017)'s analysis, and it is highly correlated with the trend of SO_2 concentration.

people are increasingly less likely to migrate out of the TCZ prefectures. This alleviating effect complements previous findings in the literature based on provincial census data, which documents a change in internal migration flow patterns after 2010. Changes in air quality in a city takes time to evolve. High-skilled people are still migrating out of highly polluted TCZ cities but at a slower rate as they are more likely to be aware that air quality is not worsening further over time.

6.3 Firm Reallocation and Impact on Wages

A possible reaction to new environmental regulations was demonstrated in the seminal work by Levinson (1996) and referred to as the Pollution Haven effect. Manufacturing firms sidestep regulations by re-establishing their plants in less regulated areas. Therefore, in the Chinese context, manufacturing during the 11^{th} FYP may move from Eastern and Northeastern to less-developed Western provinces (Wang et al., 2019; Wu et al., 2017).

On the other hand, sectoral reallocations could also result in an effect on wages. Walker (2013) shows that Clean Air Act decreased almost 20% of the pre-regulatory income for new plants. Recent work by Chen (2019) using the ASIF data finds no statistically significant evidence that air pollution regulation decreases average wages for the heavily and lightly polluting firms, despite their sizeable production activities from 1999 - 2007.

7 Robustness Checks

7.1 Alternative SO_2 Quota Formulae and Weighted Variables

One may question that the benchmark SO_2 quota from Formula 4 does not fully approximate the true picture of the SO_2 reduction efforts across prefectures. For instance, Beijing's base emission in 2005 was 191,000 million tons and was reduced to 39,000 tons within 5 years, which was similar to Inner Mongolia that was required to reduce 56,000 tons of SO_2 emission over the same time period. However, Inner Mongolia's SO_2 emission base in 2005 was 1.456 million tons, 7 times higher than that in Beijing. Holding all else constant, reducing the same amount of SO_2 may require considerably greater efforts. Hence, Formula 4 may not provide an objective guidance regarding treatment intensity under this scenario. To mitigate this concern, we use the percentage of SO_2 emission change to construct the alternative measurement, given by

$$SO_2\ Quota_{c,05-10} = \frac{SO_2\ emission_{2005,p}\ -\ SO_2\ emission_{2010,p}}{Provincial\ SO2\ emission\ 2005} \cdot \sum_{i=1}^{39} \mu_i \frac{output\ value_{i,c}}{output\ value_{i,p}},$$

in which the first faction indicates the percentage of SO_2 reduction using 2005 as the base. As an alternative, we also replace output value by the number of employees in the above formula.

The above combinations result in three additional quota intensity formulae. We next examine the sensitivity of the results using these alternate methods of constructing the regulation variable. Their summary statistics are presented in Table 1. These alternative constructions suggest a similar pattern, which is that treatment intensities in the TCZ prefectures are approximately three times higher than that in non-TCZ prefectures. We first repeat our baseline regression exercise with these three alternatives and examine whether our main results are robust to using two weighted variables: population density in urban districts and another based on whole prefecture. These results are shown in Panel A of Table 6 and reveals that the environmental regulations leads to outmigration from a regulated prefecture regardless of how SO_2 regulation is constructed. Furthermore, Panel B includes various weighted variables and fourth- and fifth-order polynomials interacted with the TCZ selection variables. These results confirm that the use of a third-order polynomial is sufficient and shows that our baseline results are robust to alternative sets of specifications.

7.2 Randomisation of the SO_2 Quota Treatment

To confirm that our results are not a "cherry-picking" activity, we randomly permute the quota intensity and placebo treatment year for the 289 prefectures and obtain new DiD estimates from the newly constructed regressor $Quota_c^{false} \times post_t^{false} \times Non\_Top10_c$. We repeat this process 1000 times for the period 2000-2010.[27] If our model is correctly specified, a null treatment effect should produce a zero policy effect. The falsification exercises are plotted in Figure 8. This figure shows that the distribution of the placebo estimate for high- and low-skilled labour centres around 0. The baseline estimate for high-skilled workers (red vertical line) is considerably away from the 1% level. This implies that our estimated effect of the SO_2 quota (0.29) on high-skill labour is almost impossible to find by chance. In contrast, the estimate for low-skilled labour is away from where it is likely to be significant, providing further support that low-skill workers are unresponsive to environmental regulations.

8 Concluding Remarks

The objective of this paper is to examine the effect of the SO_2 quota under the 11^{th} Five-Year Plan on internal migration flows in Chinese cities, and whether it redistributes high-skilled workers from the developed and more pollution regulated prefectures to the less developed and less regulated ones. Our study provides evidence that stringent environmental policies leads to outmigration from regulated cities. It further provides new evidence that an environmental policy can lead to a redistribution of the high-skilled labour force, although this was not an original aim of the policy. Our results suggest that

[27] The results are similar when we extend the sample period to 2014.

the SO_2 quota treatment effect progressively increases over time with the progression of the 11^{th} FYP but its effects fade after it ends. We find that the redistribution effects are more substantial and sustaining for the high-skilled workforce, and that the effects are larger for the workforce in non-mega prefectures.

Using spatial-temporal variation in the SO_2 regulation intensity across cities, and conditioning on a set of fixed effects and pre-treated selection controls along with an array of robustness tests, this paper provides three key findings. First, our results suggest that a 1,000 tons increase in the SO_2 emissions reduction quota leads on average to approximately a 1.5 percentage points increase in high-skilled net outmigration. Compared to the largest prefectures, the regulation effect is twice as large in the smaller regulated prefectures. Second, the event study shows that this effect is strongest at the end of regulation period before gradually diminishing after that. Third, we highlight that, in the short term, the SO_2 quota treatment effect does not operate through reducing relative labour demand in the main SO_2 emitting industry, which is the electricity supply industry. Instead, the treatment effect operates through negatively impacting demand in the other polluting industries. At the same time, we observe an increasing trend for relative labour demand of skilled occupations in the non-polluting sector. Finally, over the long term, it appears that the high-skilled workforce is less likely to migrate out of the regulated prefectures due to air quality staying at a stable level and not worsening any further.

Our results also suggest two important policy implications, especially for interested government bodies whose aim is to reduce regional development disparities. First, Chinese government officials have launched a set of ongoing regional development plans, including the rise of Central China, College-graduate Village Officials Program and the China Western Development program. Our findings suggest that environmental policies can also help redistribute high-skilled labour from second-tier cities to third-tier cities. However, it is still the case that people living in the top tier cities are reluctant to outmigrate permanently to other cities, likely due to the value of a permanent Hukou in top tier cities.

Environmental control policies can therefore help achieve a double objective of improving health and help high-skilled people redistribute around the country to contribute to the long-term economic growth of China. In other words, command-and-control environmental policies can work as a complementary tool to the government's regional development policies. Second, recent research by Chang et al. (2016) and He et al. (2018) show that air pollution decreases labour productivity in China. From this perspective, such an internal redistribution of skilled migrants out of polluted prefectures may therefore also have positive effects on overall labour productivity in China.

China is a very large and populous country and our findings are context specific. We therefore suggest caution in interpreting the degree to which the results, based on our definition in calculating skilled outmigration using China's Hukou system, generalises to the broader skilled workforce in other countries. We also suggest caution in extrapolating results from the SO_2 reduction quota on internal skilled labour migration to the effects of the regulation of other pollutants, such as Chemical Oxygen Demand, under the 11^{th} FYP. Furthermore, our study focuses on the dynamics of permanent net outmigration in response to a new environmental regulation. We do not focus on temporary migration or the location of migration choice. We leave these questions for future research.

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Table 1: Summary Statistics

Description	(1) TCZ Mean	(2) TCZ SD	(3) Non-TCZ Mean	(4) Non-TCZ SD
***Migration Variables* (2000-2014):**				
Outmigration rate of total Hukou (%)	-1.33	1.62	-1.32	2.01
Outmigration rate of high skilled workers (%)	-2.62	3.10	-2.61	3.16
Outmigration rate of low skilled workers (%)	-0.61	3.18	-0.86	2.93
Population growth rate in prefectures (‰)	5.34	4.26	6.17	4.31
Population growth rate in urban areas (‰)	4.99	3.87	6.33	4.38
SO2 Reduction Quota:				
Quota_output (10,000 tons): weighted by prefectural industrial output share in 2005	1.49	2.12	0.43	0.47
ΔQuota_output (%): in a percentage change form	1.52	2.95	0.37	0.35
Quota_emp (10,000 tons): weighted by prefectural employment share in 2005	1.42	1.82	0.50	0.50
ΔQuota_emp (%): in a percentage change form	1.45	2.82	0.44	0.35
***Sectoral Employment* (2000-2005):**				
Share of employees in primary industries (%)	2.28	4.40	6.41	10.22
Share of employees in secondary industries (%)	47.19	12.75	38.47	13.95
Share of employees in tertiary industries in urban districts (%)	50.58	11.98	55.15	13.98
Unemployment (log no. of persons)	9.93	0.79	9.49	0.74
Provincial employment share for air polluted industries (%)	3.67	4.42	1.96	3.29
***Prefecture Variables* (2000 - 2005):**				
No. of doctors (1 unit)	8893	8606	5263	3604
High school × teachers per high school student	771	778	425	358
University × teachers per student	5625	9491	1776	3501
Foreign direct investment (10,000 USD)	66312	132501	11399	28606
Green coverage rate (%)	35.60	8.90	32.87	10.71
GDP value in log (10,000 CNY)	15.89	1.12	15.25	0.94
Social commodity consumption in log (10,000 CNY)	14.82	1.18	14.08	1.00
Constructed areas (hectare)	4.42	0.88	3.86	0.66
Green land (hectare)	6653	12765	2484	3938
Value-added tax (10,000 CNY)	701760	961602	307539	491352
Total paved roads (log 10,000 m^2)	6.82	1.07	6.19	0.85
Total no. of taxis (1 unit)	3637	5397	1839	2184
TCZ Selection Variables:				
Average SO2 concentration 1990-1995 (ug/m^3)	16.63	8.64	12.50	8.53
Average elevation (metre)	309.9	462.1	455.2	1017.0
Average tempurature 1990-1995 (℃)	15.23	4.50	13.03	5.42
Sunshine duration 1990-1995 (0.1 hrs)	5.34	1.44	5.91	1.30
Average humidity 1990-1995 (1%)	0.72	0.09	0.70	0.09
Average daily precipitation 1990-1995 (0.1 mm)	10638	4984	8708	4854
Average wind speed 1990-1995 (0.1 m/s)	22.23	10.02	22.40	8.09
Percentage of days in a year no greater than 5 ℃ 1990-1995 (%)	0.17	0.15	0.24	0.16

Table 2: The Impact of SO_2 Regulations on Net Outmigration Rates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: Total net outmigration rate										
TCZ × Post2006	0.158	0.224*	0.147	0.206	0.048					
	(0.123)	(0.131)	(0.123)	(0.131)	(0.106)					
Quota × Post2006						0.074**	0.073**	0.078**	0.073*	0.024
						(0.034)	(0.036)	(0.037)	(0.038)	(0.026)
Observations	3,026	3,026	3,021	3,021	4,140	3,026	3,026	3,021	3,021	4,140
R-squared	0.403	0.418	0.407	0.421	0.354	0.404	0.418	0.408	0.421	0.355
Panel B: Low-skilled net outmigration rate										
TCZ × Post2006	-0.218	-0.123	-0.198	-0.101	-0.173					
	(0.202)	(0.213)	(0.202)	(0.226)	(0.198)					
Quota × Post2006						-0.048	-0.037	-0.039	-0.032	-0.034
						(0.112)	(0.121)	(0.117)	(0.127)	(0.097)
Observations	2,862	2,862	2,857	2,857	3,919	2,862	2,862	2,857	2,857	3,919
R-squared	0.176	0.187	0.180	0.191	0.152	0.176	0.187	0.180	0.191	0.152
Panel C: High-skilled net outmigration rate										
TCZ × Post2006	0.479*	0.313	0.526**	0.413	0.140					
	(0.255)	(0.286)	(0.253)	(0.285)	(0.218)					
Quota × Post2006						0.187**	0.141*	0.191**	0.150*	0.133
						(0.076)	(0.080)	(0.081)	(0.085)	(0.083)
Observations	2,854	2,854	2,849	2,849	3,919	2,854	2,854	2,849	2,849	3,919
R-squared	0.274	0.282	0.281	0.288	0.275	0.275	0.282	0.282	0.289	0.276
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TCZ Controls × f(t)	No	Yes	No	Yes	Yes	No	Yes	No	Yes	Yes
Prefecture Controls	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Year Coverage	2000-2010	2000-2010	2000 - 2010	2000-2010	2000 - 2014	2000-2010	2000-2010	2000 - 2010	2000-2010	2000 - 2014

Note: Standard errors are clustered by prefecture. Regressions are weighted using the proportion of the working age population at each prefecture in 2000. *** p<0.01, ** p<0.05, * p<0.1. Post2006 = 1 if year > 2006; Post2006 = 0, otherwise.

Table 3: Effects of SO_2 Regulations on Top 10 Cities

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	Low-Skilled Net Outmigration Rate				High-Skilled Net Outmigration Rate			
TCZ × Post × Top10	-1.293	-1.268			-0.862	-0.756		
	(1.431)	(1.303)			(0.633)	(0.578)		
Quota × Post × Top10			-0.044	-0.027			-0.088	-0.107
			(0.171)	(0.117)			(0.096)	(0.104)
TCZ × Post × Non_Top10	0.034	-0.041			0.519*	0.243		
	(0.238)	(0.211)			(0.270)	(0.213)		
Quota × Post × Non_Top10			-0.017	-0.033			0.290***	0.268***
			(0.168)	(0.137)			(0.088)	(0.081)
Observations	2,857	3,919	2,857	3,919	2,849	3,919	2,849	3,919
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TCZ Controls × f(t)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prefecture Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Coverage	2000-2010	2000-2014	2000-2010	2000-2014	2000-2010	2000-2014	2000-2010	2000-2014

Note: Top 10 cities are 10 most populated cities: Beijing, Shanghai, Tianjin, Chongqing, Chengdu, Shenyang, Guangzhou, Dongguan, Shenzhen, Wuhan. Non_Top10 = 1 if a city belongs to the non-Top 10 city; Top10 = 1 if a city belongs to the Top 10 city. *** p<0.01, ** p<0.05, * p<0.1. Post2006 = 1 if year > 2006; Post2006 = 0, otherwise. Standard errors are clustered by prefecture. Regressions are weighted using the proportion of the working age population at each prefecture in 2000.

Table 4: Effects of SO_2 Regulations on Relative Labour Demand on Polluting Industries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	EmpShare_Province				EmpShare_Total			
***Panel A: Six top polluting industries* (SO$_2$: 89%)**								
TCZ × Post2006	-0.030*		-0.050***		-0.011***		-0.020***	
	(0.016)		(0.019)		(0.004)		(0.005)	
Quota × Post2006		-0.011		-0.023**		-0.008***		-0.012***
		(0.009)		(0.011)		(0.002)		(0.002)
Observations	16,601	16,601	21,176	21,176	16,601	16,601	21,176	21,176
***Panel B: Electricity, heat production and supply* (SO$_2$: 59%)**								
TCZ × Post2006	0.073*		0.081		0.003		-0.007	
	(0.041)		(0.053)		(0.008)		(0.008)	
Quota × Post2006		0.022		0.010		-0.000		-0.008
		(0.028)		(0.041)		(0.005)		(0.006)
Observations	3,012	3,012	3,830	3,830	3,012	3,012	3,830	3,830
***Panel C: Non-metal mineral products* (SO$_2$: 9%)**								
TCZ × Post2006	-0.062***		-0.085***		-0.020**		-0.028***	
	(0.021)		(0.030)		(0.008)		(0.010)	
Quota × Post2006		-0.038***		-0.061***		-0.016***		-0.022***
		(0.010)		(0.021)		(0.003)		(0.004)
Observations	3,037	3,037	3,848	3,848	3,037	3,037	3,848	3,848
***Panel D: Ferrous metal smelting and pressing* (SO$_2$: 7.2%)**								
TCZ × Post2006	-0.082*		-0.133**		-0.015		-0.044***	
	(0.046)		(0.054)		(0.011)		(0.013)	
Quota × Post2006		-0.050**		-0.076***		-0.013**		-0.023***
		(0.023)		(0.023)		(0.007)		(0.006)
Observations	2,797	2,797	3,537	3,537	2,797	2,797	3,537	3,537
***Panel E: Chemical materials and products* (SO$_2$: 5.9%)**								
TCZ × Post2006	-0.005		-0.048		-0.016**		-0.020**	
	(0.029)		(0.033)		(0.006)		(0.009)	
Quota × Post2006		-0.031**		-0.035***		-0.018***		-0.019***
		(0.013)		(0.011)		(0.004)		(0.004)
Observations	3,031	3,031	3,848	3,848	3,031	3,031	3,848	3,848
Year Coverage	2000-2010	2000-2010	2000-2013	2000-2013	2000-2010	2000-2010	2000-2013	2000-2013

Note: EmpShare_Province and EmpShare_Total represent no. of employment at each industry relative to provincial and aggregate employment, respectively. All regressions are weighted and controlled for TCZ Controls*f(t), prefecture Controls and prefecture and Year FEs. *** p<0.01, ** p<0.05, * p<0.01. Standard errors are clustered by prefecture. Regressions are weighted using the proportion of the working age population at each prefecture in 2000.

Table 5: Effects of SO_2 Regulation on Relative Labour Demand in the Dirty Sector (DDD)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	EmpShare_Province				EmpShare_Total			
Panel A: Dirty industries								
TCZ × Post2006 × Dirty	-0.041**	-0.053***			-0.019***	-0.023***		
	(0.020)	(0.019)			(0.006)	(0.005)		
Quota × Post2006 × Dirty			-0.014*	-0.020*			-0.006**	-0.007**
			(0.009)	(0.011)			(0.003)	(0.003)
Observations	91,172	116,088	91,172	116,088	91,172	116,088	91,172	116,088
***Panel B: Excluding electricity, heat production and supply industry* (SO$_2$: 59%)**								
TCZ × Post2006× Dirty	-0.052***	-0.079***			-0.024***	-0.026***		
	(0.020)	(0.021)			(0.006)	(0.006)		
Quota × Post2006 × Dirty			-0.021**	-0.027**			-0.009***	-0.008***
			(0.009)	(0.011)			(0.003)	(0.003)
Observations	88,123	112,207	88,123	112,207	88,123	112,207	88,123	112,207
City-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City-Ind FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Coverage	2000-2010	2000-2013	2000-2010	2000-2013	2000-2010	2000-2013	2000-2010	2000-2013

Note: Dirty is industry dummy. 1 if a industry belongs to top 6 polluting industries. All regressions controls for two-way industry-year, prefecture-year and prefecture-industry fixed effects. All regressions are weighted using the proportion of working age population at each prefecture in 2000.. *** p<0.01, ** p<0.05, * p<0.01. Standard errors are clustered by prefecture-industry level.

Table 6: Different Quota Intensity Measurements and Alternative Weights

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	Low-Skilled Net Migration Rate				High-Skilled Net Migration Rate			
Panel A: Alternative quota measurements								
Quota% × Post2006 × Non_top10	-0.129				0.380***			
	(0.213)				(0.100)			
Quota_emp × Post2006 × Non_top10		-0.017				0.290***		
		(0.168)				(0.088)		
Quota_emp% × Post2006 × Non_top10			-0.144				0.461***	
			(0.235)				(0.120)	
Observations	2,857	2,857	2,857		2,849	2,849	2,849	
R-squared	0.191	0.191	0.191		0.291	0.291	0.291	
Panel B: Alternative weights and time trends								
Quota × Post2006 × Non_top10								
(Pop. density as a weighting variable)	-0.106				0.312***			
	(0.158)				(0.083)			
Quota × Post2006 × Non_top10								
(Working age population as weighting variable)		-0.006				0.327***		
		(0.166)				(0.093)		
Quota × Post2006 × Non_top10								
(4^{th} Polynomial)			-0.029				0.282***	
			(0.176)				(0.089)	
Quota × Post2006 × Non_top10								
(5^{th} Polynomial)				-0.030				0.280***
				(0.176)				(0.089)
Observations	2,857	2,857	2,857	2,857	2,849	2,849	2,849	2,849
R-squared	0.211	0.198	0.196	0.198	0.272	0.287	0.294	0.297
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TCZ Controls × f(t)	Yes	Yes	Yes (4th)	Yes (5th)	Yes	Yes	Yes (4th)	Yes (5th)
Prefecture Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Coverage	2000- 2010	2000- 2010	2000- 2010	2000- 2010	2000- 2010	2000- 2010	2000- 2010	2000- 2010

Note: Quota% is SO_2 quota in a percentage form using output as a weight. *Quota_Emp* is SO_2 quota using employment as a weight. *Quota_Emp%* is SO_2 reduction quota in a percentage form using employment as a weight. TCZ Controls × f(t) is the 3^{rd} order polynomial time trends interacting with TCZ selection variables. $4^{th}/5^{th}$ Polynomial indicates the 4^{th} or 5^{th} order polynomial time trends interacting with TCZ selection variables. *Pop. density* denotes population density. Post2006 is 1 if year >2006; 0, otherwise. *** p<0.01, ** p<0.05, * p<0.01. Standard errors are clustered by prefecture-industry level. All regressions are weighted.

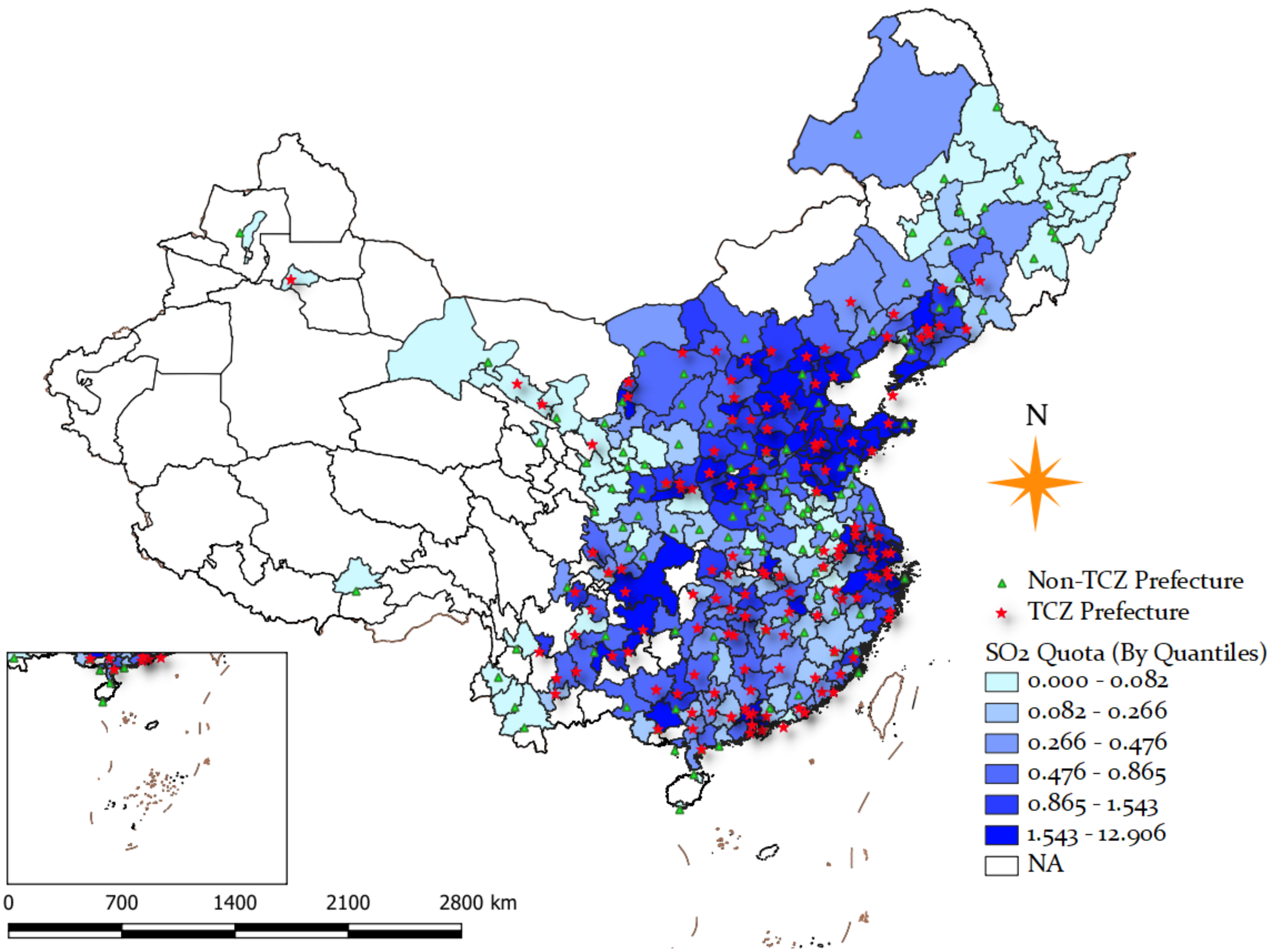


Figure 1: Distribution of Two-Control Zones and SO_2 Quota Stringency

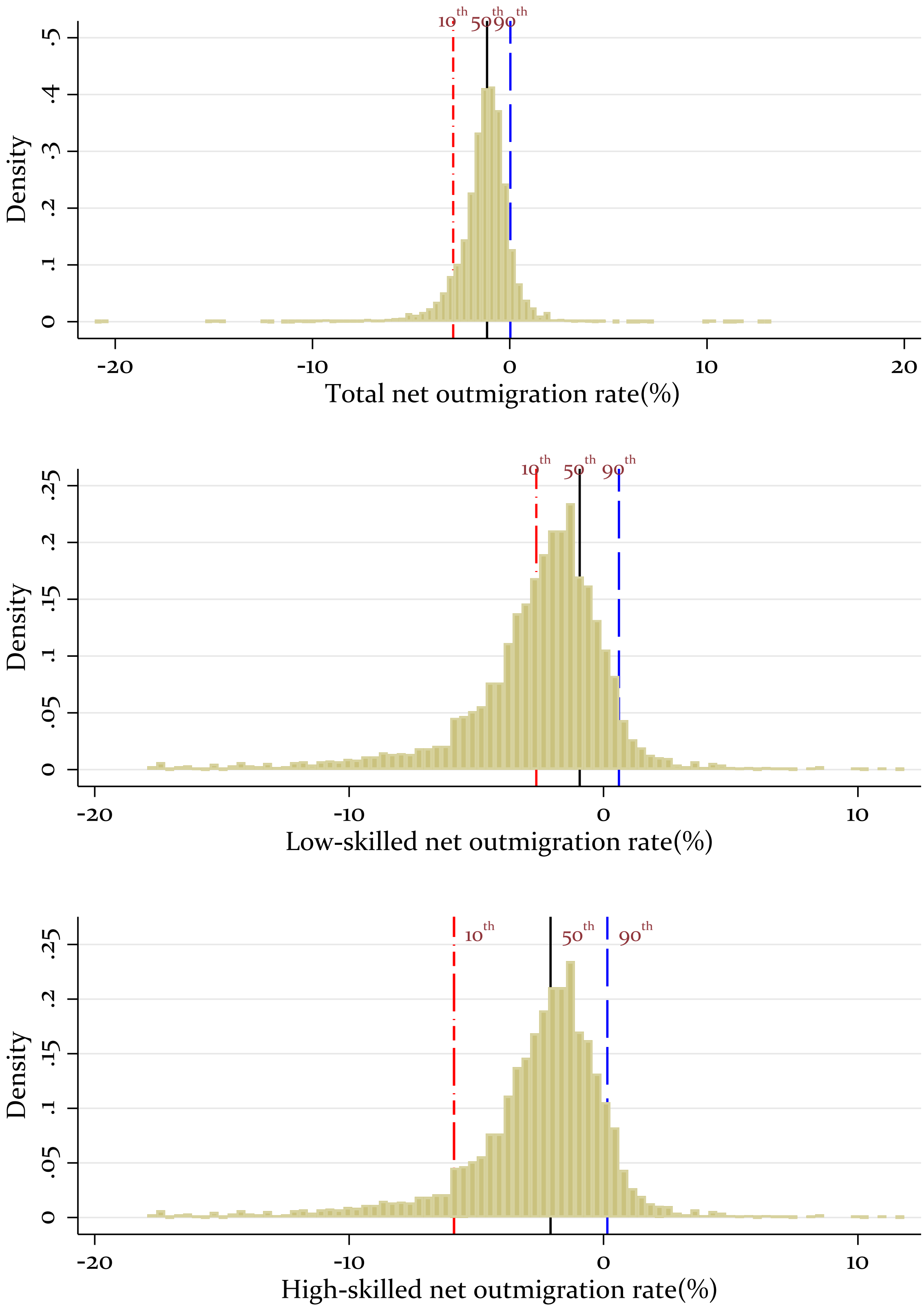


Figure 2: Histogram of Net Outmigration Rate for 3 Categories of Hukou Holders

Note: The 10^{th}, 50^{th} and 90^{th} percentiles of three different categories of Hukou holders are plotted in the figure.

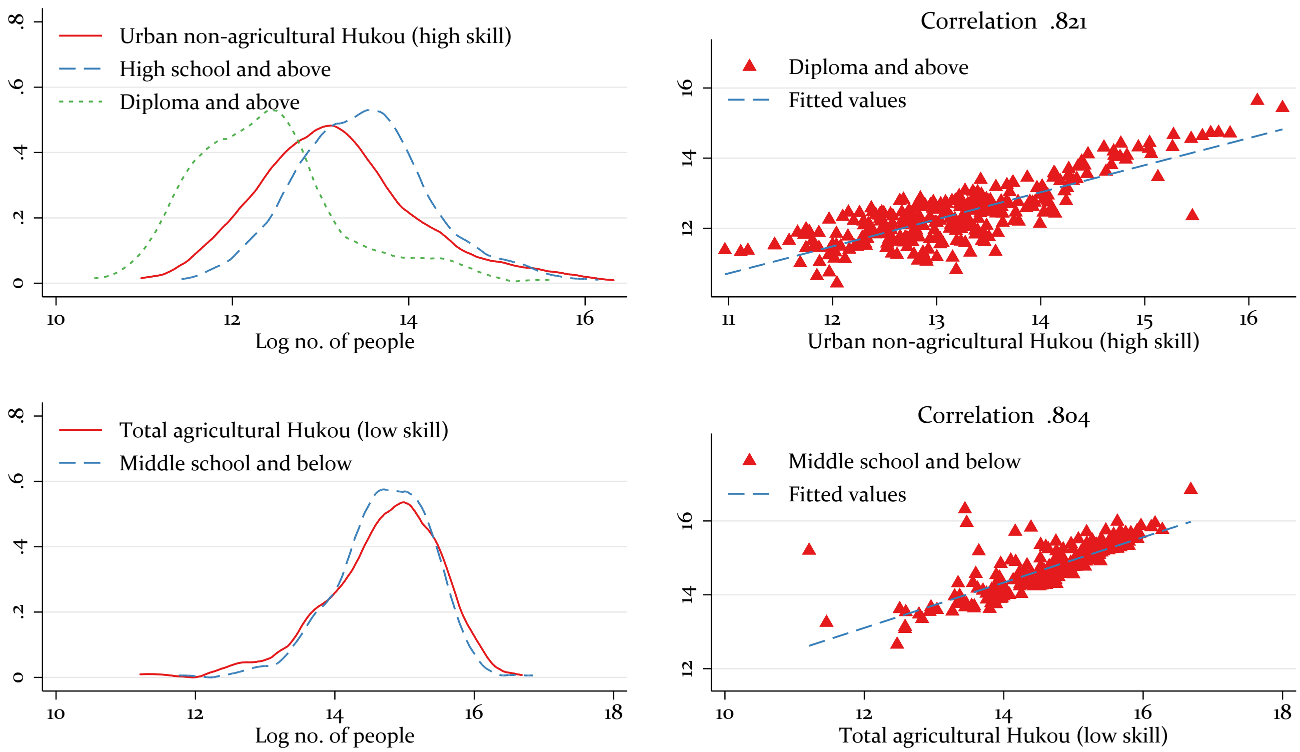


Figure 3: Hukou and Education Attainments in 2010 Population Census

Note: This figure compares the correlations of high- and low-skilled workers (defined by two types of Hukou) against educational attainments which are commonly used in the literature to define high-skill labour (e.g. Meng (2016) defines high-skill labour as workers with at least a high school education. One the other hand, Khanna et al. (2019) define high-skill as college education or above). The top two graphs suggest that the density of non-urban agricultural Hukous in urban districts is somewhere between the density plots for high school and diploma degrees. Furthermore, urban non-agricultural Hukou depicts a strong correlation with diploma and above educational attainments across the 289 prefectures. In contrast, in the bottom two graphs, low skilled workers, defined using agricultural Hukou, is strongly correlated with lower educational attainment (middle school and below). A further correlation exercise shows that the correlation of agricultural Hukou with urban non-agricultural Hukou, diploma and bachelor are 0.053, 0.194 and 0.0548 respectively. This exercise suggests that our definition of low-skilled workers does not capture any notions of high-skill. Data of educational attainments for 289 prefecture cities is collected from 31 provincial 2010 Population Census books.

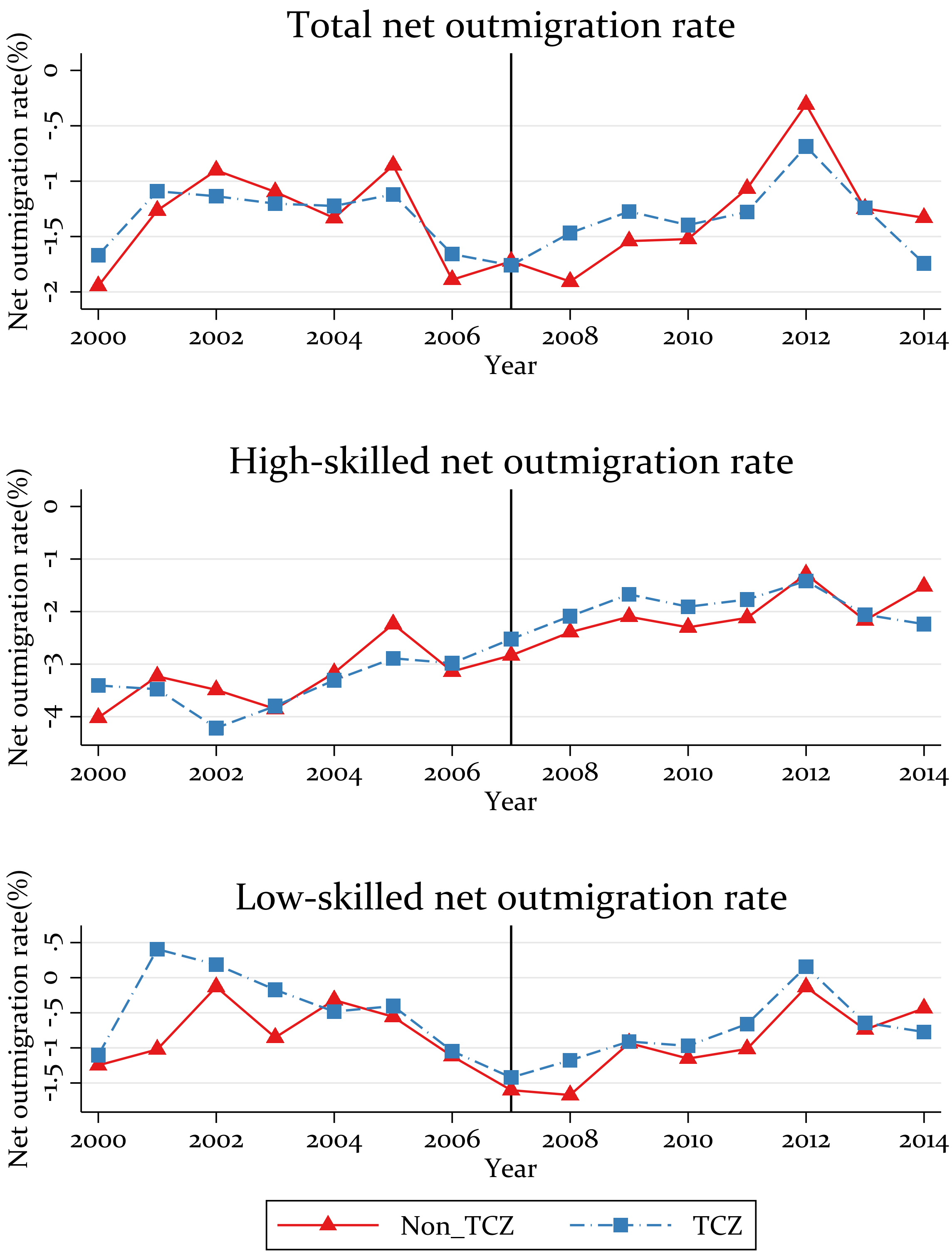


Figure 4: Time Trends of Average Net Outmigration Rates for 3 Categories of Hukou Holders (by TCZ status)

Note: Total outmigration rate is calculated based on total Hukou change. Low-skilled outmigration rate is calculated based on total rural Hukou movement. High-skilled outmigration rate is based on non-agricultural Hukou movement in the urban areas.

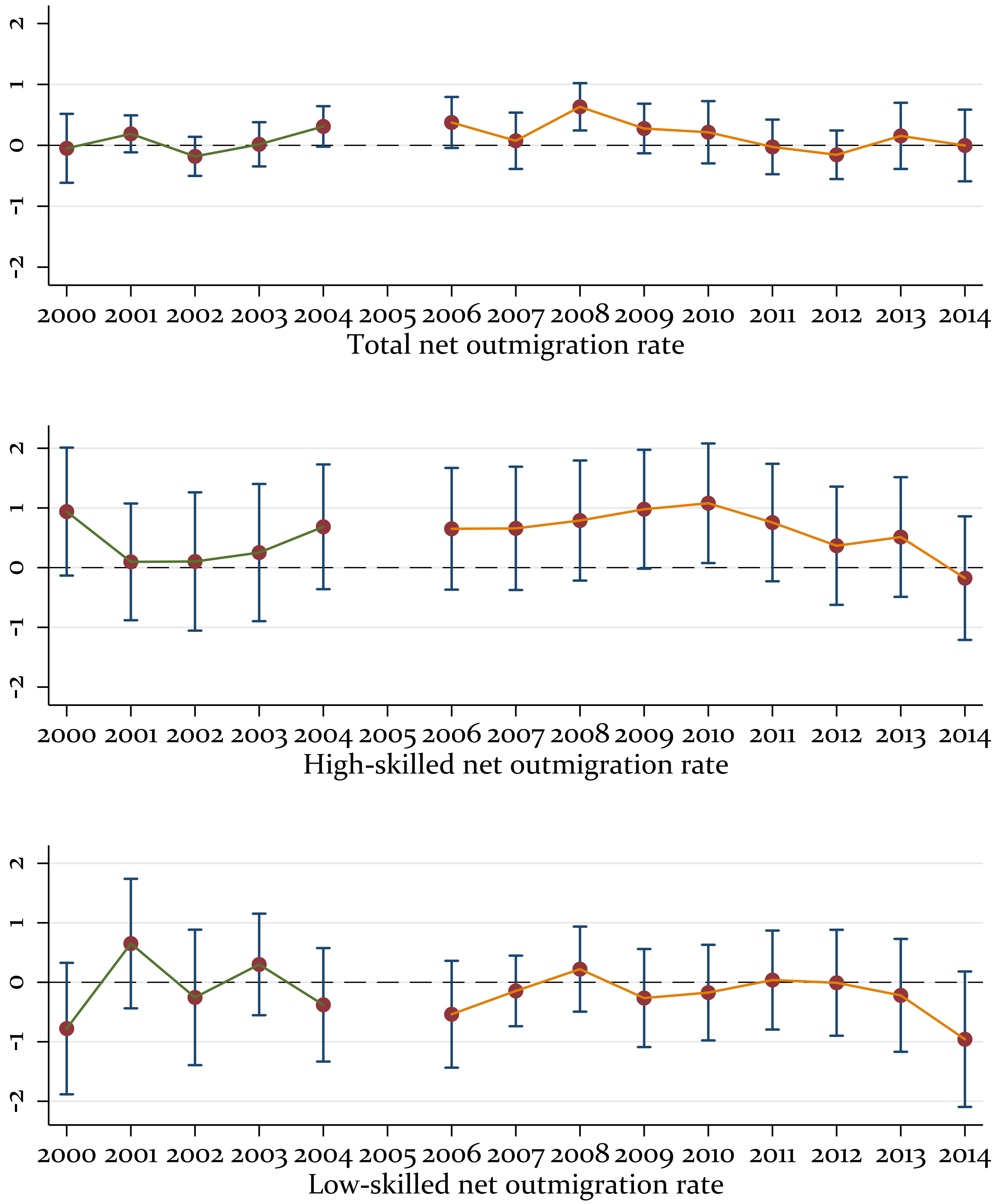
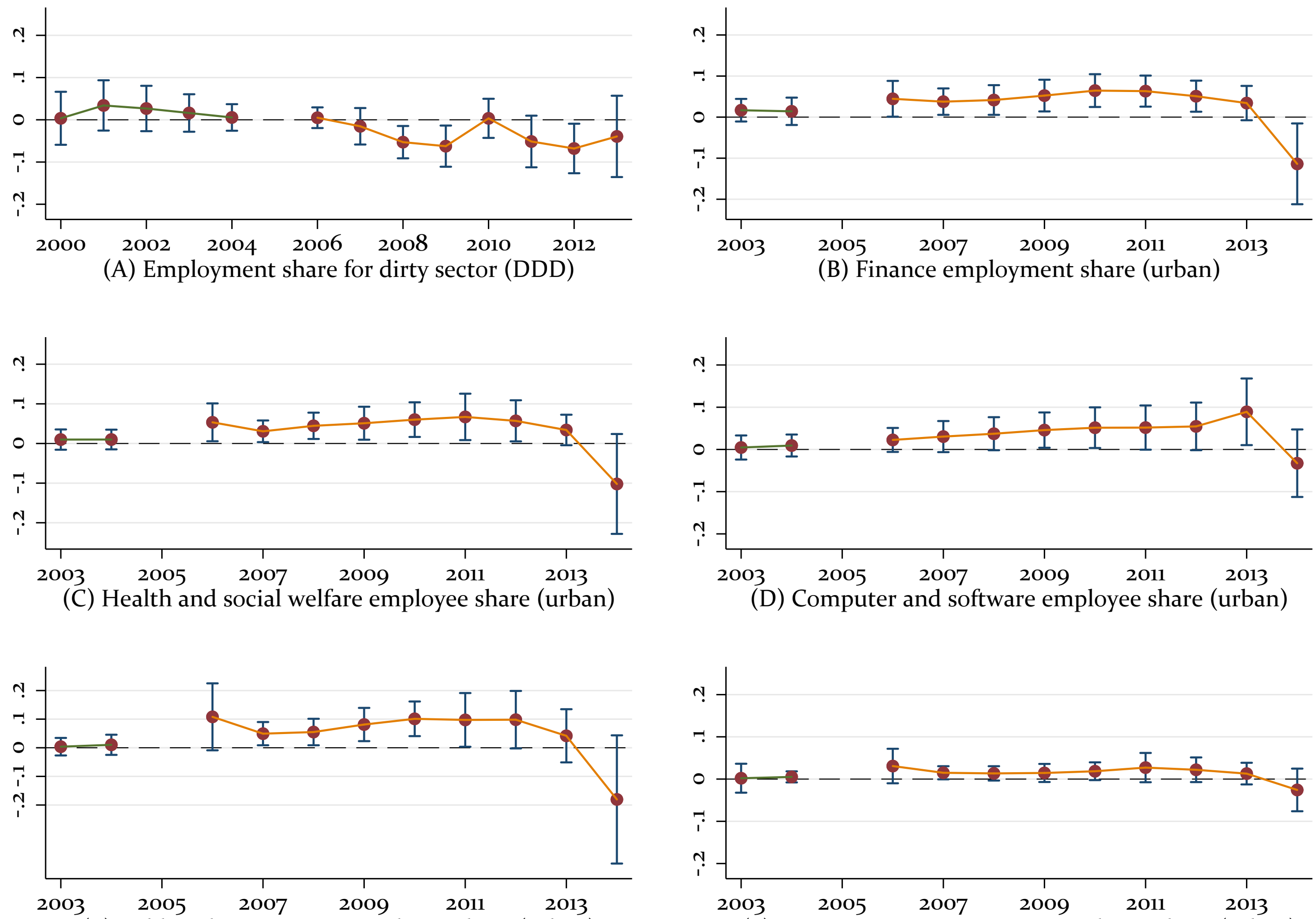


Figure 5: Regulation Effects and Net Outmigration Rates in Non-top 10 Cities

Note: This figure plots coefficients with 95% confidence intervals and illustrates estimates of year prior to and after SO_2 regulation for net outmigration rates in non-top 10 Cities. The reference category is year 2005. High-skilled net outmigration rates are calculated based on urban agricultural Hukous. The low-skilled outmigration does not differentiate between the urban and rural populations. A summation of low-skilled and high-skilled net outmigration rates are not equal to total net outmigration rates.



(A) Employment share for dirty sector (DDD)

(B) Finance employment share (urban)

(C) Health and social welfare employee share (urban)

(D) Computer and software employee share (urban)

(E) Public administration employee share (urban)

(F) Environment mangement employee share (urban)

Figure 6: Sectoral Employment Transitions for Skilled Occupations and Dirty Sector (95% coefficient plots)

Note: This figure plots coefficients with 95% confidence intervals for the employment shares of five skilled occupations and the SO_2 polluting (dirty) sector. The reference category is year 2005. Data for the dirty sector is available from 2000 to 2013 and for the high-skilled jobs is available from 2003 to 2014. Estimates for the dirty sector in Panel A are obtained by estimating $Dirty\_EmpShare\_Province_{i,c,t} = \sum_{j=2000}^{2013} \beta_j (TCZ_c \times Year_j \times Dirty_i) + \delta_{ct} + \gamma_{ic} + \lambda_{it} + \epsilon_{i,c,t}$. Estimates for Panel B-F are estimated using $Skilled\_EmpShare\_Province_{c,t} = \sum_{j=2003}^{2013} \beta_j (TCZ_c \times Year_j) + \mathbf{X_{ct}}\beta_2 + \mathbf{Z_c} \times \mathbf{f}(\mathbf{t}) + \delta_c + \lambda_t + \epsilon_{c,t}$.

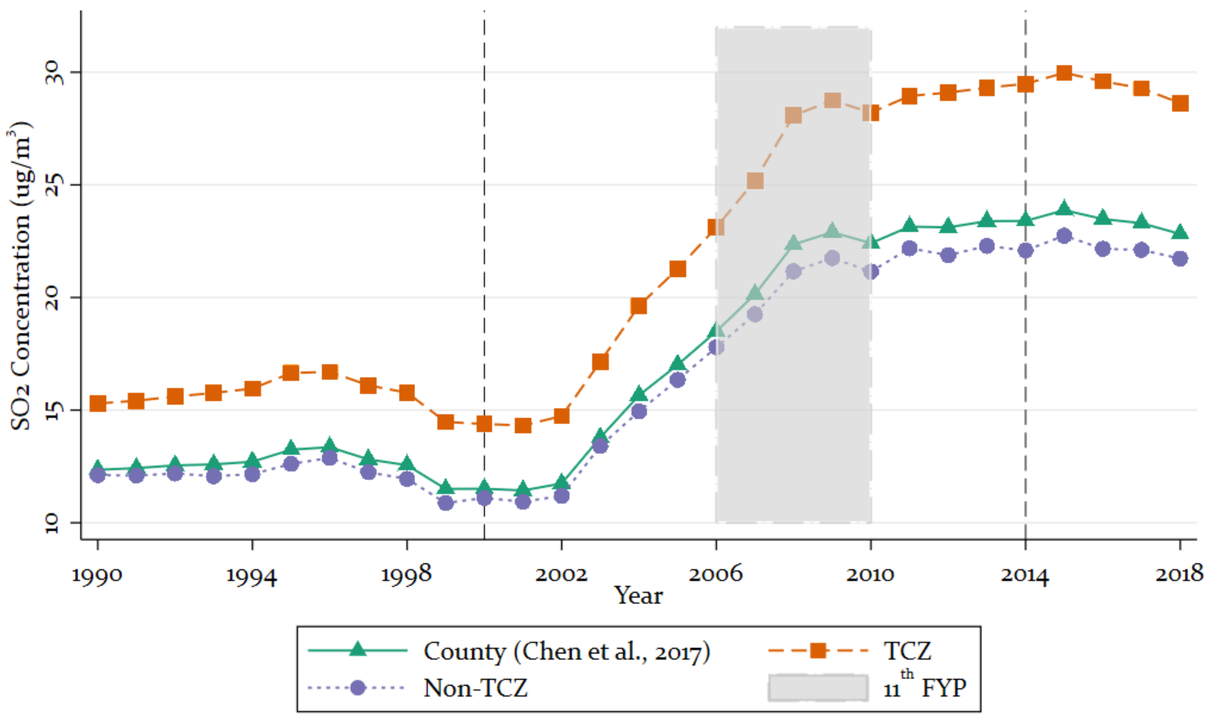


Figure 7: SO_2 Concentration in TCZ and Non-TCZ Prefectures

Note: The overall county-level SO_2 trends are obtained by using monthly NASA MERRA-2 data averaged across 2859 counties and was downloaded from the Ministry of Civil Affairs of the P.R.C. It replicates the trend seen in Chen et al. (2017)'s study using county level data. *TCZ* and *NTCZ* represent average SO_2 concentration levels for the TCZ and Non-TCZ prefectures, respectively. The two black lines in the graph depict the sample period in our study, 2000-2014. The shaded area highlights the period of the 11^{th} FYP.

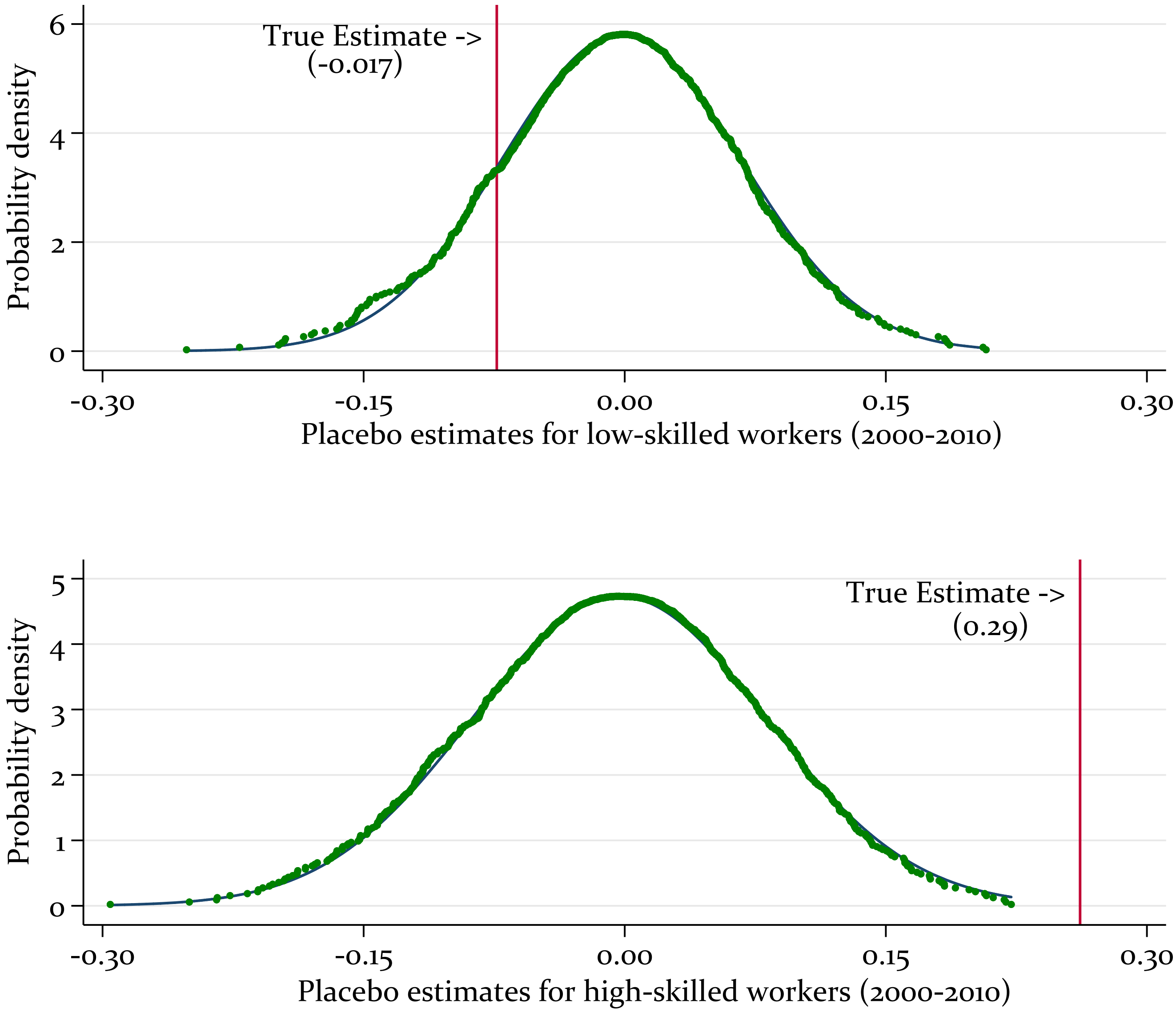


Figure 8: Placebo Treatment of Environmental Regulation

Note: This figure plots the distribution of the 1000 estimated coefficients via randomly assigning the false treatment and year. The vertical line indicates the benchmark estimates in Table 3.

Appendix: Additional Tables and Figures

Table A1: Provincial SO_2 Emissions Reduction Quotas in 2005

Province	Actual Emissions in 2005 (10,000 tons)	Planned Emissions in 2010 (10,000 tons)	Actual Emssions in 2010 (10,000 tons)	Reduction Achievement Status
Shanghai	51.3	38	35.8	Achieved
Beijing	19.1	15.2	11.5	Achieved
Shandong	200.3	160.2	153.8	Achieved
Jiangsu	137.3	112.6	105	Achieved
Hebei	149.6	127.1	123.4	Achieved
Guizhou	135.8	115.4	114.9	Achieved
Zhejiang	86	73.1	67.8	Achieved
Guangdong	129.4	110	105.1	Achieved
Henan	162.5	139.7	133.9	Achieved
Shanxi	151.6	130.4	124.9	Achieved
Shaanxi	92.2	81.1	77.9	Achieved
Liaoning	119.7	105.3	102.2	Achieved
Chongqing	83.7	73.7	71.9	Achieved
Sichuan	129.9	114.4	113.1	Achieved
Guangxi	102.3	92.2	90.4	Achieved
Tianjin	26.5	24	23.5	Achieved
Ningxia	34.3	31.1	31.1	Achieved
Hunan	91.9	83.6	80.1	Achieved
Fujian	46.1	42.4	40.9	Achieved
Hubei	71.7	66.1	63.3	Achieved
Jiangxi	61.3	57	55.7	Achieved
Jilin	38.2	36.4	35.6	Achieved
Anhui	57.1	54.8	53.2	Achieved
Yunnan	52.2	50.1	50.1	Achieved
Inner Mongolia	145.6	140	139.4	Achieved
Heilongjiang	50.8	49.8	49	Achieved
Qinghai	12.4	12.4	14.3	Not Achieved
Hainan	2.2	2.2	2.9	Not Achieved
Tibet	0.2	0.2	0.4	Not Achieved
Gansu	56.3	56.3	55.2	Achieved
Xinjiang	51.9	51.9	58.8	Not Achieved

Table A2: Industrial SO_2 Emissions Intensity in 2005

Industry_ID	Two-digit industry	Year	SO2 weight
44	Electricity, heat production and supply industry	2005	58.935%
31	Non-metal mineral products	2005	9.006%
32	Ferrous metal smelting and pressing	2005	7.182%
26	Chemical materials and products	2005	5.896%
25	Petroleum and nuclear fuel processing	2005	3.577%
33	Non-ferrous metal smelting and pressing	2005	3.570%
22	Pulp and paper production	2005	2.178%
17	Textile	2005	1.496%
99	Other industry	2005	1.332%
6	Coal Mining and Dressing	2005	1.062%
13	Agricultural products and byproducts	2005	0.788%
28	Chemical fiber	2005	0.582%
15	Beverage production	2005	0.538%
14	Food production	2005	0.472%
9	non-ferrous metals mining	2005	0.338%
27	Medical and pharmaceutical products	2005	0.324%
10	nonmetal minerals mining	2005	0.288%
35	General appliances manufacturing	2005	0.280%
20	Processing of wood, bamboo, and straw	2005	0.242%
29	Rubber products	2005	0.224%
8	ferrous metal mining	2005	0.218%
37	Transportation appliances manufacturing	2005	0.207%
36	Special appliances manufacturing	2005	0.166%
7	Power production	2005	0.163%
39	Electric appliances manufacturing	2005	0.137%
34	Metal products	2005	0.129%
19	Leather, furs, feathers and related products	2005	0.107%
45	Gas Production and Supply	2005	0.095%
40	Electronic appliances manufacturing	2005	0.086%
18	Garments manufacture	2005	0.077%
30	Plastic products	2005	0.066%
41	Office appliances manufacturing	2005	0.066%
16	Tobacco products	2005	0.065%
46	The production and supply of water	2005	0.027%
42	Handicrafts manufacturing	2005	0.025%
21	Furniture manufacturing	2005	0.018%
24	Cultural and sports appliances	2005	0.014%
23	Printing	2005	0.013%
11	Other mining industry	2005	0.012%
43	Recycling and disposal of waste	2005	0.002%

Table A3: Balancing Tests

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Non-TCZ		**TCZ**					
VARIABLES	Mean	SD	Mean	SD	Unconditional Difference	**Conditional Difference (Prior)**	**Conditional Difference (11^{th} FYP)**	**Conditional Difference (Whole)**
High school student/teachers in urban districts (%)	17.461	0.905	16.304	0.231	1.156	-0.668	0.465	-0.051
Doctor*hospital beds/hospital no. (log unit)	11.621	0.093	12.255	0.098	-.634***	-0.030	0.034	0.067
Green coverage rate (%)	27.358	1.050	29.253	0.769	-1.895	0.301	-1.041	-0.805
Prefecture GDP value (log 10,000 CNY)	14.358	0.064	14.913	0.072	-0.555***	-0.029	-0.012	-0.013
Social commodity consumption (log 10,000 CNY)	13.279	0.072	13.921	0.076	-0.642***	0.059	0.010	-0.003
Constructed areas (log hectare)	3.558	0.057	3.985	0.062	-0.427***	-0.012	-0.031	-0.016
Green land (log hectare)	6.815	0.086	7.344	0.087	-0.529***	-0.024	-0.040	-0.058
Retail sale (log billion CNY)	13.123	0.092	13.991	0.110	-0.868***	0.109	-0.016	-0.038
Total paved roads (log KM^2)	5.552	0.076	6.041	0.072	-0.489***	0.006	0.016	0.019
Urban unemployment (log no. of persons)	8.411	0.091	8.963	0.087	-0.664***	0.144	-0.010	-0.055
Year coverage	2000		2000		2000	2000	2000-2010	2000-2014

Note : Column (6) represents regressions of each variable on a TCZ dummy, controlling for the TCZ selection variables and prefecture economic variables indicated as above. In columns (7) and (8), we regress each of above variables on TCZ*Post conditional on the TCZ selection variables, prefecture and year fixed effects, and other control variables. *** p<0.01, ** p<0.05, * p<0.01. Standard errors are clustered by prefecture. All regressions are weighted.