

ONLINE APPENDIX: NOT FOR PUBLICATION

We outline a partial equilibrium model to explore the underlying mechanisms that drive the relationship between pollution and hours worked.

0.1 Labor Supply and Air Quality

We consider a partial equilibrium framework where individuals maximize utility with respect to consumption, c , and hours worked, e . We assume utility is given by $u = u(c, e; \alpha)$ and is separable in c and e . Note that e is a “bad,” so $u_e < 0$, while $u_c > 0$. We assume that the utility function is concave, i.e. that $u_{cc} < 0$ and $u_{ee} < 0$.

We model air quality, α , as an argument of the utility function that affects the marginal utility of both consumption and hours worked. We focus on the partial effects of air quality on hours worked, and therefore we assume that exposure to air quality is exogenous.¹ Specifically, we hypothesize that better air quality increases a worker’s health as well as the health of his or her dependents, making it less costly for the worker to devote time to work. In other words, better air quality lowers the disutility of work: $u_{e\alpha} > 0$.² The relationship between air quality and consumption is ambiguous. For example, if improved air quality increased the utility derived from additional consumption (i.e. better air quality may improve the utility derived from amusement park visits or shopping outdoors), then consumption and air quality would be complements: $u_{c\alpha} > 0$. However, better air quality could also reduce the marginal utility derived from consumption ($u_{c\alpha} < 0$). This would be the case if, for example, asthma medication or gym memberships were substitutes for clean air.

¹Relaxing this assumption would affect the observed results in the following manner: Suppose that there are two neighborhoods, and one of the neighborhoods experiences a permanent reduction in pollution. The area that experienced the air quality shock could attract individuals whose marginal utility for clean air is higher than the marginal utility of the previous residents of the affected area. The resulting observed change in hours worked depends on whether the newcomers have a high marginal disutility of work with respect to air quality or whether they have a high marginal value for consumption given a certain level of air quality. The newcomers could experience stronger changes in hours worked than the leavers if the strong preferences for air quality are predominantly linked to a reduction in the disutility of work. If newcomers have higher consumption value for air quality, but do not experience additional reductions in the disutility of work, the change in hours of work could be smaller for the newcomers. We revisit this issue in the empirical section, and test for the presence of differential migration into the areas surrounding the refinery after the closure.

²You could also argue the opposite assumption, that better air quality produces a net increase in the disutility of work ($u_{e\alpha} < 0$). This may result, for example, if individuals who work in offices would rather be outside in a low pollution environment. This is unlikely to happen in our empirical framework since we measure the effect of pollution on the hours of work in the following week, and only contemporaneous air quality makes leisure more attractive. Our empirical results are largely consistent with the predictions yielded by $u_{e\alpha} > 0$.

We can rewrite the optimization problem faced by the individual using the indirect utility function:

$$\max v(e) = \lambda(\alpha) \cdot we - g(e; \alpha) \quad (1)$$

where w is the wage rate at time t . Note that for tractability, we assume the individuals are wage-takers, and the wage is unaffected by pollution; we discuss the implications of these assumptions in Section 2.2. The marginal utility of lifetime income along the optimal path is represented by $\lambda(\alpha)$; this term captures changes in the value of income stemming from individual reoptimization decisions on both consumption and hours worked. Finally, $g(e; \alpha)$ can be interpreted as the disutility of hours worked given a certain level of air quality:

$$g(e; \alpha) = - \int_0^e u_e(x; \alpha) dx \quad (2)$$

Note that the assumption $u_{e\alpha} > 0$ translates into $g_{e\alpha} < 0$. Similarly, the concavity assumption for the utility translates into a convexity assumption for $g(e; \alpha)$, since the marginal disutility of work increases with hours ($g_{ee} > 0$).

Optimal work hours for a given level of air quality, α , are the solution to the first order condition for (1):

$$g_e(e; \alpha) = \lambda(\alpha)w$$

Given additive separability of hours of work and consumption, the change in hours worked as air quality increases is given by:

$$\frac{de}{d\alpha} = \frac{-g_{e\alpha} + \frac{\partial \lambda}{\partial \alpha} w}{g_{ee}} \quad (3)$$

The change in hours of work with respect to pollution depends on the sign of the two terms in the numerator of (3). The first term captures the “substitution effect” stemming from a reduction in the disutility of work. This term will be unambiguously positive since the disutility of work is decreasing in air quality.

The second term in the numerator of (3) can be interpreted as an “income effect.” On net, we expect this effect to be negative. Intuitively, this term incorporates several effects. First, as income

rises with more hours worked, we would expect the disutility of work to increase relative to the utility of consumption. Second, as air quality improves, the marginal utility of income ($\lambda(\alpha)$) will change as a result of a new optimal level of consumption. Better air quality may reduce the marginal utility gain from consumption if consumption is predominantly a substitute for air quality (individuals would work less, as consumption goods are less valuable with better air quality). If the income effect is large enough to dominate the substitution effect, the overall effect of pollution on work hours may even be negative.

It is important to note, however, that there are also cases where the income effect may be positive, thereby amplifying the substitution effect. If air quality is predominantly a complement of consumption, the marginal utility of income ($\lambda(\alpha)$) could increase with improved air quality, thus increasing work hours (intuitively, individuals would work more in order to purchase consumption goods, as the value of the goods rises with improved air quality). A positive income effect would result in an unambiguous increase in hours worked.

In sum, the partial equilibrium model predicts that high air quality should result in an increase in hours worked, unless a negative income effect dominates.³ Next, we relax the simplifying assumption above that pollution does not affect worker productivity, and explore how changes in productivity may affect hours worked.

0.2 Productivity effects

Worker productivity may improve as air quality improves. If wages reflect the marginal productivity of hours worked, higher work productivity would result in higher wages. Assume wages depend on air quality, α , through the following function:

$$w(\alpha) = f_1(e \cdot \phi(\alpha), K)\phi(\alpha) \tag{4}$$

where $f_1(\cdot, K)$ is the marginal productivity of labor efficiency units for given capital K , and $\phi(\alpha)$ is the number of labor efficiency units per hour of work. Assume further that air quality increases

³Note that, in a general equilibrium framework, aggregate labor supply may be mechanically affected as individuals supply more hours of work as air quality improves. This shift would lead to a new labor market equilibrium with lower wages and more aggregate hours of work. However, because the equilibrium wage would fall, the increase in hours of work would be smaller than in the case where wages did not change.

the productivity of hours worked, which yields $\frac{\partial}{\partial \alpha} \phi(\alpha) > 0$.⁴ For simplicity, assume homogeneity of degree one in the production function. Then, in equilibrium, $f_1(e \cdot \phi(\alpha), K) = s_L$ and

$$\frac{\partial w(\alpha)}{\partial \alpha} = s_L \frac{\partial}{\partial \alpha} \phi(\alpha) > 0 \quad (5)$$

Higher wages will have two additional effects on labor supply besides the ones discussed above: a wage substitution effect and a wage income effect. The first effect is unambiguously positive, while the second effect is unambiguously negative. Unless labor supply is downward sloping (which implies a dominating income effect), the productivity effect will increase labor supply beyond what the Equation 3 describes.

⁴Crocker and Horst (1981) and Graff and Neidell (2011) find a negative empirical relationship between air pollution and productivity. Frankenberg et al. (2005) estimate that haze from fires in Indonesia caused older adults to be more likely to report having difficulty carrying a heavy load than older adults in non-haze areas. In addition, there is a large medical literature linking iron supplements, which improve respiratory functioning, to productivity (for example, see Davies et al., 1984; Haas and Brownlie, 2001; Zhu and Haas, 1998; Woodson et al., 1978). In turn, there is evidence from experimental studies that iron supplements can improve work output and productivity (Basta et al., 1979; Thomas et al., 2003; Li et al., 1994).