LETTER

Applying statistical models to the climate–migration relationship

We are grateful to Auffhammer and Vincent (1) for having pointed out that Eqs. **1** and **2** in Feng et al. (2) do not represent the model actually used to produce the estimates presented in Tables 1 and 2 of the latter paper (2). What we actually estimated was a model without time dummies. Thus, g_t and h_t should have been omitted from Eqs. **1** and **2**. We regret this mistake.

However, despite the omission of time dummies, the results presented in our paper are still informative. Panel data models with and without time dummies are both potentially valid statistical models. The key identifying assumption in our earlier study is that within-state climate variability, which is arguably exogenous, is uncorrelated with the error term in the main equation for migration. This argument applies regardless of whether time dummies are included in the model or not.

That said, we fully concur with the concern expressed by Auffhammer and Vincent over possible confounding effects resulting from variables omitted from the regression equation. Controlling for national trends by adding time dummies could alleviate this particular concern, but other confounders could remain because one is never entirely sure what effects are captured by the error term. Furthermore, some climate variations potentially useful in identifying the parameter would be excluded by adding time dummies. Therefore, using a model including time dummies has both benefits and costs.

In our particular case, adding a time dummy would eliminate more than 90% of the climate variation used in the estimation. Thus, the statistical model with a time dummy yields very imprecise estimates, as shown by Auffhammer and Vincent. On the other hand, the potential benefit of including a time dummy, which is the avoidance of possible omitted variable bias, seems modest. We explored various robustness checks in our paper (2) and found that the key migration elasticity is relatively robust. For example, we excluded border states of Mexico in row F of Table 2 in Feng et al. (2) to address the concern that the North American Free Trade Agreement could have affected areas adjacent to the United States differently. Furthermore, we conducted a new robustness check by including gross domestic product (GDP) growth rate as an additional explanatory variable to control for time-related effects and found the results to be qualitatively unaffected, as shown by Table 1.

Table 1. Robustness results, with or without controlling for GDP growth

Yield statistic	FE-2SLS	FE-LIML
Not controlling for GDP growth		
Corn	−0.211*	−0.225*
	(0.036)	(0.042)
Corn plus wheat	−0.183*	−0.214*
	(0.036)	(0.051)
Controlling for GDP growth		
Corn	−0.162*	−0.193*
	(0.044)	(0.041)
Corn plus wheat	−0.116*	−0.142†
	(0.038)	(0.056)

Not controlling for GDP growth replicates main results reported in Table 1 of Feng et al. (2), whereas controlling for GDP growth controls additionally for 5-y GDP growth rate at the state level. Robust standard errors are reported in parentheses. FE-2SLS, fixed-effects two-stage least squares. FE-LIML, fixed-effects limited-information maximum likelihood.
*Significance at the 1% level.
†Significance at the 5% level.

Table 2. Results for the 16 more rural states, with or without controlling for a time dummy

Yield statistic	FE-2SLS	FE-LIML
Without a time dummy		
Corn	−0.157*	−0.166*
	(0.011)	(0.013)
Corn plus wheat	−0.182*	−0.194*
	(0.015)	(0.019)
With a time dummy		
Corn	−0.139*	−0.178*
	(0.017)	(0.027)
Corn plus wheat	−0.157*	−0.212*
	(0.021)	(0.039)

"Without a time dummy" replicates results from Feng et al. (row E of Table 2 in ref. 2) and "with a time dummy" presents new results when time effects are controlled for. Robust standard errors are reported in parentheses.
*Significance at the 1% level.

Finally, for the 16 more rural Mexico states, where the yield–migration link is more likely to hold, results are robust to whether a time dummy is controlled for, as illustrated by Table 2. For the fixed-effects limited-information maximum-likelihood (FE-LIML) specification, which is a more robust estimator when sample size is small, the estimated coefficients become even larger after controlling for a time dummy.

In conclusion, we thank Auffhammer and Vincent for having pointed out the error in Eqs. **1** and **2** of our study (2). Nevertheless, given the costs and benefits of including a time dummy, along with the other evidence presented here, we believe the results presented in our original paper (2) are informative and provide evidence of a climate–migration relationship.

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