

Supplementary Material

Table S1 Definition of variables in estimating propensity score

Variables	Definition
Migration	=1 if the household has at least one member living outside the county for at least six months for employment purposes; =0 otherwise
Land certificate	=1 if the village issues land certificates to households in the 1998 land contracting; =0 otherwise
Land reallocation	=1 if the village reallocated land at least once after the 1998 land contracting; =0 otherwise
Household head age	Age of household head
Household head education level	Education level of household head
Average age of adults	Average age of adults (aged 16 years old and above, and excluding those who are still students)
Average education level of adults	Ratio of adults having taken junior high school or higher to all adults in the household
Average off-farm employment experience of adults	Ratio of adults with off-farm experience in the year before last to all adults in the household
Household size	Number of household members
Female ratio	Ratio of female adults
Number of adults	Number of household members aged 16 years old and above
Dependency ratio	The number of family members aged over 65 or below 16 divided by family size
Village official	Household head is or was a village official
Land area per capita	Area of contracted land per capita (mu)
Number of land plots	Number of contracted land plots
Possession of houses	The number of houses the household owns in the year before last
Possession of machinery	=1 if the household possesses machinery the year before last; =0 otherwise
Distance to town centre	Distance to township centre (km)

Jiangsu	=1 if the household is from Jiangsu; =0 otherwise
Liaoning	=1 if the household is from Liaoning; =0 otherwise
Chongqing	=1 if the household if from Chongqing; =0 otherwise

Table S2 Descriptive statistics of variables in the production function

Variable	Unit	Mean	S.D.	Min.	Max.
Yield	Kg/household	4111.28	6993.148	135	56000
Fertilizer	Kg/household	230.64	394.1123	3.68	3072.8
Land	Ha/household	0.55	0.9	0.02	7.47
Machine	Yuan ¹ /household	685.73	1478.8	0	16855
Labour	Labour days/household	39.29	128.31	0.33	3120
Pesticide	Yuan ¹ /household	758.23	1511.4	0	22400
Soil quality	From 1 (= low quality) to 5 (= high quality)	3.26	0.92	1	5
Irrigation condition	From 1 (= low quality) to 5 (= high quality)	3.22	1.12	1	5
Double-season rice	=1 if a household produces double-season rice; =0 otherwise	0.28	0.45	0	1

Note: ¹. 1 US dollar is about 6.69 yuan according to the exchange rate in August 2016.

Table S3 Descriptive statistics and comparison of variables for estimating participation in migration

Variables	Control	Treatment	Difference ¹	Mean ²	Std. Dev. ²	Min ²	Max ²
	Migration=0	Migration=1					
Migration	--	--	--	0.43	0.50	0	1
Land certificate	0.65	0.68	-0.03	0.66	0.47	0	1
Land reallocation	0.45	0.36	0.09**	0.41	0.49	0	1
Household head age	56.15	57.79	-1.64**	56.85	9.45	23	83
Household head education level	2.66	2.59	0.07	2.63	0.99	1	6
Average age of adults	51.01	46.19	4.82***	48.95	8.71	29.33	74.33
Average education level of adults	0.54	0.61	-0.07***	0.57	0.33	0	1
Average off-farm employment experience of adults	0.54	0.66	-0.13***	0.59	0.31	0	1
Household size	3.83	4.89	-1.06***	4.29	1.74	1	15
Female ratio	0.49	0.48	0.01	0.49	0.12	0	1
Number of adults	2.98	3.87	-0.88***	3.36	1.16	1	9
Dependency ratio	0.22	0.24	-0.02	0.23	0.19	0	0.75
Village official	0.26	0.25	0.01	0.26	0.44	0	1
Land area per capita	2.28	1.22	1.06***	1.83	2.63	0	35
Number of land plots	8.36	8.22	0.13	8.32	7.22	0	45
Possession of houses	1.19	1.16	0.03	1.18	0.44	0	4
Possession of machinery	0.34	0.25	0.09**	0.30	0.46	0	1
Distance to town centre	5.11	5.67	-0.56*	5.36	4.19	0	26

Jiangsu	0.21	0.22	-0.01	0.21	0.41	0	1
Liaoning	0.09	0.07	0.03	0.08	0.27	0	1
Chongqing	0.24	0.32	-0.07**	0.27	0.45	0	1

Note: ¹ Differences are tested by a two-sided unpaired t-test of means or proportion. ² Values of mean, “std. dev.”, min and max apply to the full sample.

*** Significant at the 1% level; ** Significant at the 5% level; * Significant at the 10% level (hereafter the same).

Table S4 Estimated results of the production function

Variables	Coef.	z
ln(Fertilizer)	0.13	0.71
ln(Land)	1.31***	4.74
ln(Pesticide)	-0.11	-1.29
Zero pesticide ¹	-0.03	-0.25
ln(Machinery)	-0.04	-0.94
Zero machinery ¹	0.004	0.06
ln(Labour)	-0.14	-1.63
0.5(ln(Fertilizer)) ²	-0.03	-1.28
0.5(ln(Land)) ²	0.11*	1.84
0.5(ln(Pesticide)) ²	0.0005	0.05
0.5(ln(Machinery)) ²	0.002	0.33
0.5(ln(Labour)) ²	0.01*	1.69
ln(Fertilizer)× ln(Land)	0.01	0.31
ln(Fertilizer)× ln(Pesticide)	0.01	1.01
ln(Fertilizer)× ln(Machinery)	0.001	0.2
ln(Fertilizer)× ln(Labour)	0.01	0.34
ln(Land)× ln(Pesticide)	-0.03**	-2.26
ln(Land)× ln(Machinery)	-0.01	-0.72
ln(Land)× ln(Labour)	-0.03*	-1.72
ln(Pesticide)× ln(Machinery)	0.004*	1.65
ln(Pesticide)× ln(Labour)	0.01	0.95
ln(Machine)× ln(Labour)	0.003	0.71
Soil quality	0.02**	2.04
Irrigation condition	0.01**	2.17
Double-season rice	-0.02	-0.6
Jiangsu	0.24***	7.21
Liaoning	0.20***	4.77
Chongqing	0.10***	3.62
Constant	9.14***	13.43
Sample size	809	

Log likelihood	329.32
Wald Chi2(28)	30569.42***

Note: ¹. Following the technique proposed by Battese (1997), the dummy variables for zero values of pesticide and machine were added to correct for zero values of inputs in an unbiased way.

We clustered standard errors at the village level.

Table S5 Output elasticities with respect to each input at sample means¹

	Elasticity
Fertilizer	0.029
Land	0.95
Pesticide	-0.082
Machine	0.047
Labour	-0.001
Scale elasticity	0.95

Note: ¹. To better understand the results of production function, we present the output elasticities of the other inputs and scale elasticity. The output elasticity with respect to fertilizer is calculated according to Eq. (9). The output elasticities with respect to other inputs (τ_{ij}) is calculated with $\tau_{ij} = \beta_j + \sum_k \beta_{jk} \ln X_{ik} + \beta_{jf} \ln F_i + \beta_{jj} \ln X_{ij}$. The scale elasticity (L_i) is calculated with $L_i = \tau_i + \sum_j \tau_{ij}$.

Table S6 Influencing factors of migration

Variables	Coef.	Z
Land certificate	-0.24	-0.93
Land reallocation	-0.28	-1.05
Household head age	0.04***	3.46
Household head education level	-0.02	-0.19
Average age of adults	-0.09***	-5.00
Average education level of adults	0.01	0.03
Average off-farm employment experience of adults	0.87***	2.60
Household size	-0.32**	-2.43
Female ratio	0.21	0.32
Number of adults	0.90***	5.03
Dependency ratio	0.56	0.99
Village official	-0.15	-0.71
Land area per capita	-0.16**	-2.02
Number of land plots	-0.005	-0.32
Possession of houses	-0.50**	-2.15
Possession of machinery	-0.32	-1.59
Distance to town centre	0.04	1.31
Jiangsu	0.13	0.46
Liaoning	0.42	0.87
Chongqing	0.49	1.52
Constant	-0.009	-0.01
Observations ¹		746
Log likelihood		-403.53

Note: We cluster standard errors at the village level.

1. Deleting observations with missing information of migration and its influencing factors, the data of 746 households are used for propensity score matching.

Table S7 Descriptive statistics of treated and control groups after matching

Variables	Mean		t ¹
	Treated	Control	
Land certificate	0.68	0.70	-0.38
Land reallocation	0.36	0.40	-1.03
Household head age	57.65	57.87	-0.3
Household head education level	2.59	2.58	0.2
Average age of adults	46.28	46.13	0.27
Average education level of adults	0.61	0.62	-0.65
Average off-farm employment experience of adults	0.66	0.66	0.09
Household size	4.87	4.96	-0.73
Female ratio	0.48	0.47	0.73
Number of adults	3.83	3.89	-0.68
Dependency ratio	0.24	0.25	-0.54
Village official	0.25	0.25	0.09
Land area per capita	1.23	1.22	0.1
Number of land plots	8.19	7.88	0.55
Possession of houses	1.16	1.22	-1.55
Possession of machinery	0.26	0.26	-0.13
Distance to town centre	5.67	5.42	0.71
Jiangsu	0.22	0.25	-0.92
Liaoning	0.07	0.08	-0.58
Chongqing	0.32	0.30	0.41

Note: ¹. A t-test is used to determine if the sample means are significantly different between treated and control groups. The results of the t-test show that none of the means are significantly different between treated and control groups.

Table S8 Number of treated and untreated households on/off support

	Off support ¹	On support
Treatment: migration		
Untreated	0	427
Treated	5	314
Treatment: less intensive migration, ≤ 0.5		
Untreated	0	427
Treated	1	250
Treatment: more intensive migration, > 0.5		
Untreated	0	427
Treated	6	62

Note: ¹. A treated household is on support if its propensity score is within the scope of propensity scores of all non-treated households; otherwise, it is off-support.

Table S9 Stochastic frontier analysis using the Cobb-Douglas production function

Variables	Coef.	Z
ln(Fertilizer)	0.04**	2.19
ln(Land)	0.96***	39.91
ln(Pesticide)	0.004	0.35
Zero pesticide	-0.06	-1
ln(Machinery)	0.01*	1.95
Zero machinery	0.05	1.41
ln(Labour)	-0.01	-0.75
Land quality	0.02*	1.83
Irrigation condition	0.01**	2.24
Double-season rice	-0.02	-0.86
Jiangsu	0.23***	7.56
Liaoning	0.22***	4.81
Chongqing	0.11***	3.74
Constant	8.49***	58.1
Observation	809	
Log likelihood	312.29	
Wald Chi ² (18)	22635.10	

Note: We clustered standard errors at the village level.

Table S10 Technical efficiency using the Cobb-Douglas production function

	Technical efficiency	Fertilizer use efficiency
Mean ¹	0.92 (0.03)	0.14 (0.08)
Minimum	0.76	0.001
25 th percentile	0.9	0.08
50 th percentile	0.92	0.14
75 th percentile	0.93	0.18
Maximum	0.97	0.5

Note: ¹. The standard deviations are in parentheses.

Table S11 The causal effect of migration and its intensity on technical efficiency and fertilizer use efficiency using radius matching

	Treated	Control	Difference ¹	S. E.
<i>Treatment: migration</i>				
Technical efficiency	0.9141	0.9182	-0.0041***	0.0017
Fertilizer use efficiency	0.2113	0.2211	-0.0098***	0.0041
Observations	314	427		
<i>Treatment: less intensive migration, ≤ 0.5 migrants</i>				
Technical efficiency	0.9144	0.9182	-0.0038**	0.0019
Fertilizer use efficiency	0.2122	0.2211	-0.0089**	0.0045
Observations	250	427		
<i>Treatment: more intensive migration, > 0.5 migrants</i>				
Technical efficiency	0.9128	0.9182	-0.0054 [†]	0.0036
Fertilizer use efficiency	0.2076	0.2211	-0.0135 [†]	0.0084
Observations	62	427		

Note: ¹. A t-test is used to identify the differences in outcomes between treatment households and their matching partners.

[†] Significant at the 15% level.

Table S12 The effect of migration on output and fertilizer use intensity (kg/ha)

	Treated	Control	Difference ¹	S. E.
<i>Treatment: migration</i>				
Land productivity	7266	7606	-340.85***	144.46
Fertilizer use intensity	408	413	-5.43	18.78
Observations	314	427		

Note: 1. A t-test is used to identify the differences in outcomes between treatment households and their matching partners.

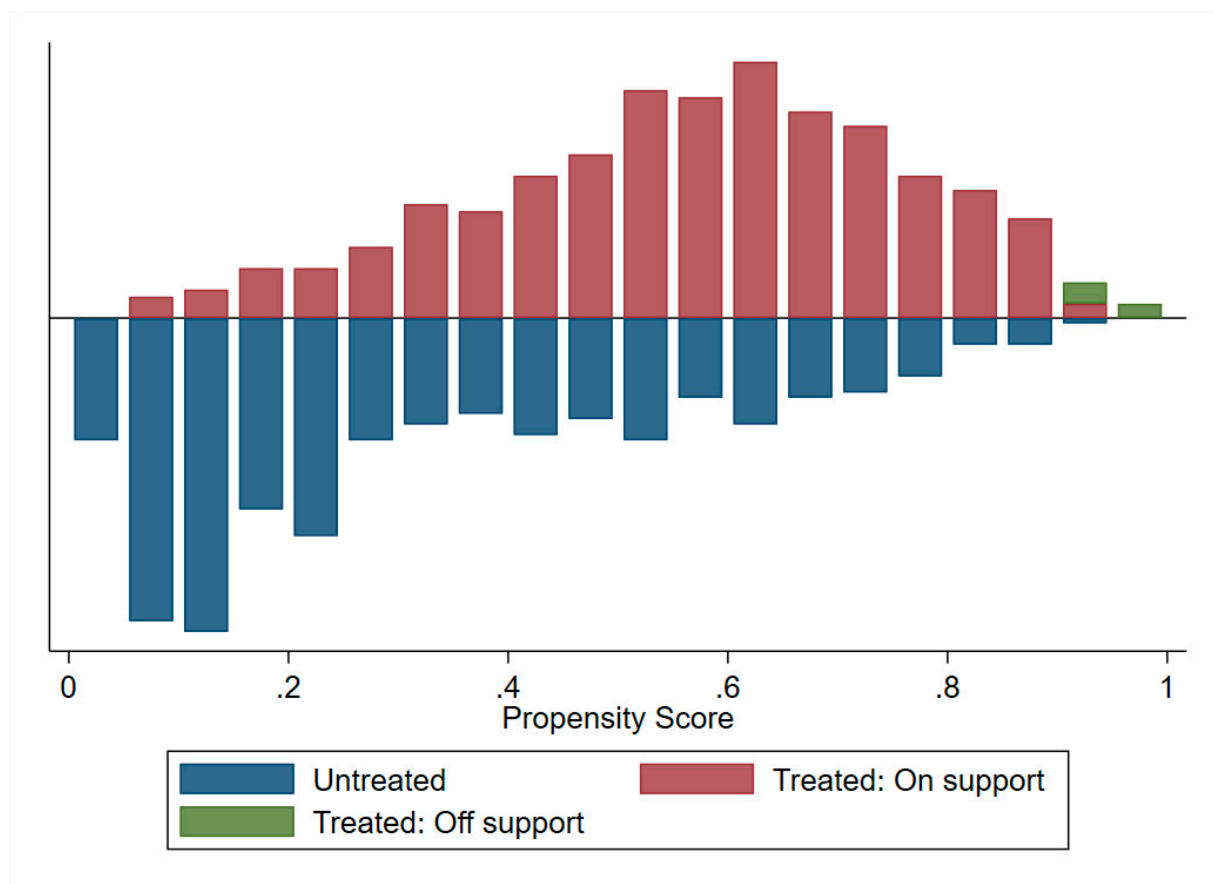


Figure S1 Distribution of pair-wise propensity score (treatment: migration)

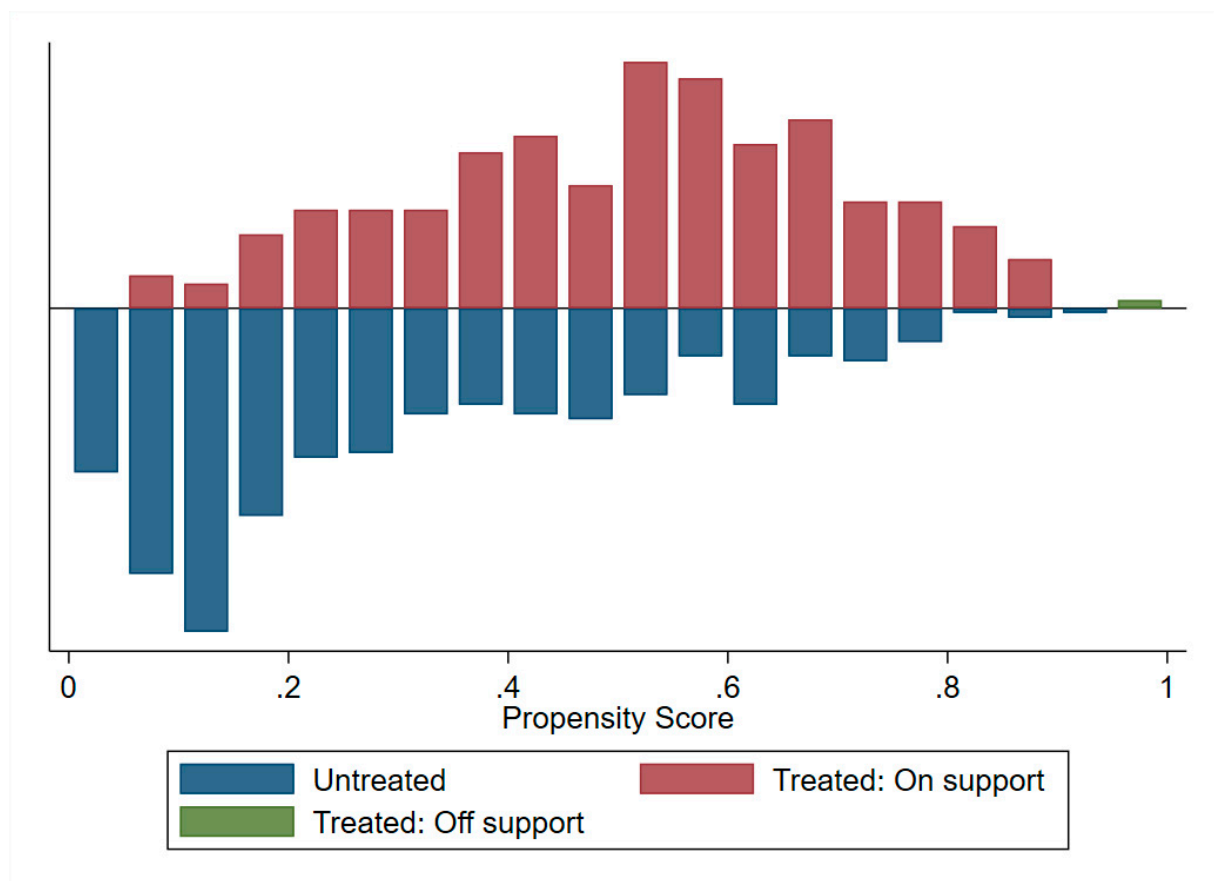


Figure S2 Distribution of pair-wise propensity score (treatment: less intensive migration)

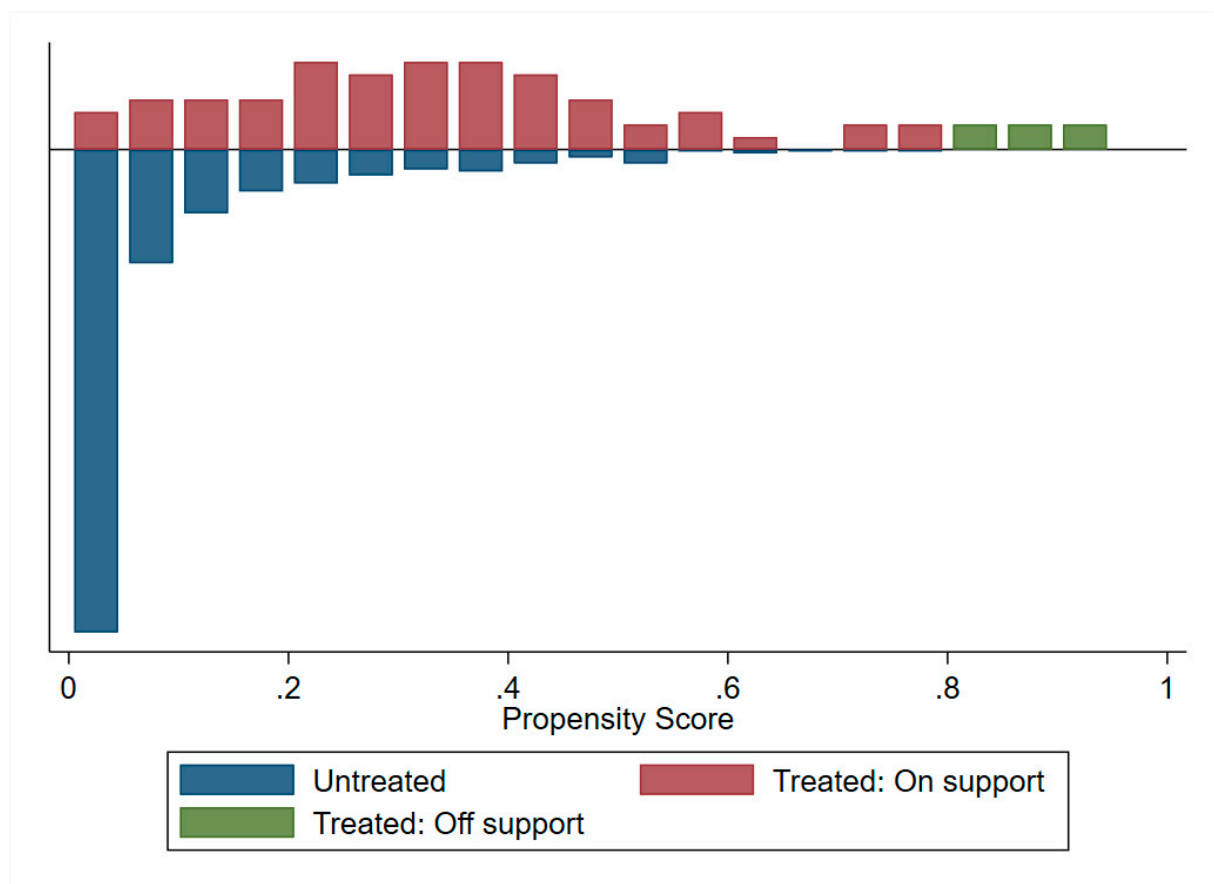


Figure S3 Distribution of pair-wise propensity score (treatment: more intensive migration)