Commodity Markets, Informal Transfers and Consumption Risk Sharing

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Abstract

Although milk production is *state-dependent* and varies with weather conditions, households would generally prefer to smooth consumption. High perishability of milk implies that rural households can only rely on buying and selling in the local markets and informal transfers for consumption smoothing. In this paper, we study risk sharing in milk consumption for a panel of households from rural India. We find that household milk consumption is insured from 80 percent of the shocks to milk production most of which is due to milk purchases and sales in the local market. We do find evidence of informal transfers playing a role, but the quasi-insurance provided by them is small in magnitude. Given the strong seasonal nature of milk production and supply, we observe informal transfers playing a more important role in the winter season for larger farmers. Availability of new roads, however, offset consumption smoothing via informal transfers in the flush season, possibly because of increased access to distant markets leading to a higher private cost of informal transfers.

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1. Introduction

Production risk is a common feature of rural environments in developing countries (Rosenzweig 1988). Rural households in risky environments typically produce for subsistence hence output variability has direct consequences for food consumption and welfare. Rural communities, however, have developed various informal mechanisms to smooth consumption (Alderman and Paxson 1994; Fafchamps 2011). A large body of literature has shown that social co-insurance in the form of informal transfers within village communities, neighbors, family or kinship networks is an important channel through which households smooth consumption (Fafchamps 1992; Fafchamps and Lund 2003; De Weerdt and Dercon 2006; Fafchamps and Gubert 2007a,b). Although the importance of informal insurance in such settings is well known, another potential and less studied channel through which rural households can smooth consumption is by trading in the local commodity markets. The role of commodity markets may be especially important when the commodity in question is highly perishable and non-storable. In the case of a storable commodity, even with imperfect risk pooling, intertemporal transfers can help smooth consumption (Deaton, 1992; Kazianga and Udry 2006; Ábrahám and Laczó 2018). Perishability, however, makes intertemporal consumption smoothing an impossibility.

In this paper, we study consumption risk-sharing among milk-producing households in rural India. Milk is highly perishable, and rural households generally lack the technology to store it for long periods (Bachmann 1985; Rajendran and Mohanty 2004). Non-storability implies that intertemporal transfer of milk to smooth consumption is typically impossible. Milk production, however, is highly variable as the lactation cycle of dairy animals is sensitive to the local weather conditions (Sirohi and Michaelowa 2007; Key and Sneeringer 2014). Moreover, milk production is typically correlated with crop production and off-farm income-earning opportunities in rural villages due to the productivity effects of weather and other shocks that affect all sectors simultaneously (Birthal and Negi 2012; Perez-Mendez et al. 2019; Thornton and Herrero 2014). Therefore, a *bad* state of the world in the form of drought and subsequent crop failure will also typically adversely influence milk production. Although milk production may be state-dependent, households would generally prefer to smooth consumption. The non-storability of milk implies, however, that rural households can only rely on sales and purchases through local markets and mutual insurance by way of informal transfers for consumption smoothing. Moreover, there is a tradeoff between own consumption and selling to the market (Alderman 1987; Pingali 1997). This tradeoff depends on the structure of rural dairy markets and the state of the world (Alderman 1987, 1994; Cunningham 2009). To what extent rural households depend on markets versus non-market risk-sharing arrangements for consumption smoothing is not apparent and is an empirical question.

We use data from the latest rounds of the Village Dynamics in South Asia (VDSA) panel household surveys to test for milk consumption smoothing at the household level (ICAR-ICRISAT 2010). These households are purposely sampled from some of the most economically backward and vulnerable regions of the country and are dependent on cultivation and livestock activities for livelihood and food security. Households face exogenous shocks to own milk production that are correlated with broader income shocks. We use the canonical social planner-based consumption risk-sharing model to first test for optimal risk-sharing in milk consumption. We then quantify the contribution of different milk sale and purchase channels, as well as non-market inter-household transfers to consumption smoothing. The canonical endowment-based risk-sharing model fits well to study consumption risk-sharing in a highly perishable and generally non-storable commodity like milk.

Evidence from the literature suggests that high trade frictions and transaction costs can impede risk sharing in developing countries (Fitzgerald 2012; Jack and Suri 2014). In the case of a commodity like fluid milk, however, lower trade frictions in the form of better road infrastructure can make distant markets accessible leading to a higher private cost of informal transfers within the village. Better access to distant markets could also lead to a higher possibility of consumption smoothing via risk spreading across previously inaccessible distant markets. Access to distant markets, therefore, may have the potential to enhance consumption smoothing but can also compete with the pre-existing forms of informal insurance mechanisms. The targeted rule-based road upgradation and construction under the Pradhan Mantri Gram Sadak Yojana (PMGSY) provides the appropriate natural experiment to answer some of these questions. We combine village-level exogenous variation in road connectivity due to the PMGSY to study how enhanced connectivity and lower trade frictions influence risk sharing and consumption smoothing for households in our sample.

We find that the efficient risk-sharing hypothesis is rejected for VDSA households. Although dairying households do not achieve complete risk-sharing, on average, household milk consumption is insured from around 80 percent of the shocks to milk production. A striking finding is that the majority of consumption smoothing is achieved through milk purchases and sales in the local markets, not via informal transfers among households. We do find evidence of informal transfers playing a role, but the quasi-insurance provided by them is small in magnitude. We find that smaller farmers rely more on market purchases and larger surplus-producing farmers rely more on sales to smooth consumption. The presence of new roads enhances this distinction with larger farmers relying even less on purchases and more on sales for consumption smoothing. Given the strong seasonal nature of milk production and supply, we also observe some seasonal patterns. Informal transfers seem to play a more important role in consumption smoothing in the winter season for larger farmers. New roads, however, offset consumption smoothing via informal transfers in the flush season possibly because of increased access to distant markets and a higher private cost of informal transfers.

Risk-sharing tests have been a popular means to study how households in high-risk environments pool risks (Townsend 1994; Grimard 1997; De Weerdt and Dercon 2006; Vanderpuye-Orgle and Barrett 2009). The focus has been on informal transfers as the primary means of risk pooling and mutual insurance, ignoring the possibility that households might simultaneously use market transactions to stabilize consumption, buying when they have a shortfall in production for own consumption and selling when they have a surplus. We add to this literature by testing efficient consumption risk-sharing in milk and quantifying the role of informal transfers vis-a-vis trade in local commodity markets in total risk-sharing. Among these semi-subsistence rural Indian households, market participation – as either buyer or seller – appears the dominant way in which people smooth milk consumption over time in the face of stochastic production and prices.

The rest of the paper is structured as follows. The next section presents the details on the data sources and the summary statistics. Section 3 presents the empirical framework. Section 4 presents the results. The last section concludes.

2. Data and summary statistics

(a) Data

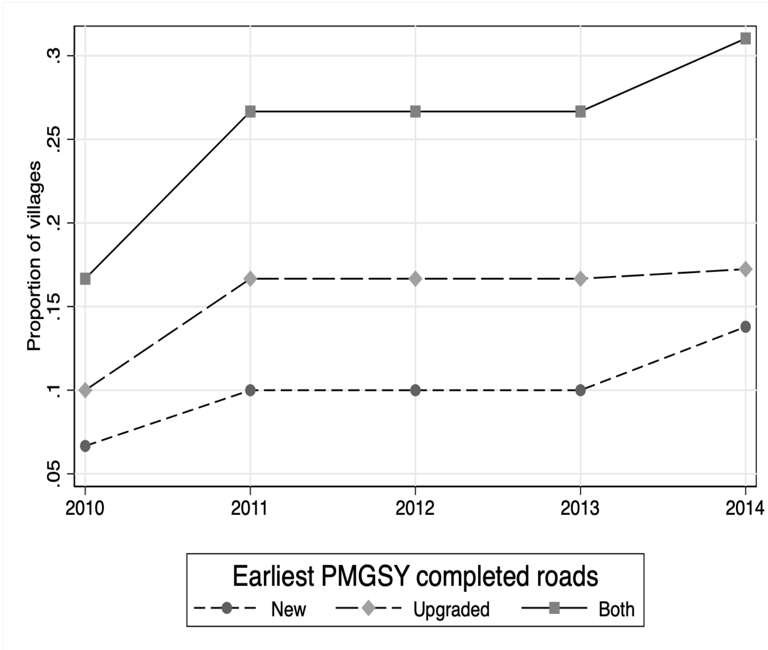
The primary data for this paper come from the Village Dynamics Studies in South Asia (VDSA) surveys. These surveys were conducted by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and focused on studying village economies in agroecologically and economically vulnerable regions of India (ICAR-ICRISAT 2010). The recent rounds of the dataset cover 30 villages across three eastern states of Bihar, Jharkhand, and Orissa, and five states of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, and Maharashtra in semi-arid tropical regions of the country. The sampled villages are mapped in Appendix Figure A1. Recently these surveys have been used to study long-term productivity growth and the relationship between scale of operations and farm productivity in agriculture (Michler 2020; Foster and Rosenzweig 2022).

The VDSA surveys collected detailed information at monthly frequency on household milk consumption – divided among home-produced, market-purchased, and transfers received from others – and on herd size and milk production quantities by species – i.e., buffaloes, cows, goats, and sheep. The surveys record the unit values in the consumption module and the price at which the milk will be sold in the production module. Out of the total milk output, 52 percent comes from cows and 44 percent is from buffaloes. Only 4 percent of milk output comes from small ruminants like sheep and goats. The survey also records information on the sale of milk by the households.

Our monthly panel data includes monthly milk consumption by source, production, herd size, milk sales, household size and value of total consumption for around 1300 households for a five-year period from 2010 to 2014.

To study how a reduction in trade costs influences consumption smoothing, we exploit variation in road construction and upgradation under the Pradhan Mantri Gram Sadak Yojana (PMGSY) or the Prime Minister's Village Road Construction Scheme. The PMGSY was started in early 2000s to provide rural all-weather roads to unconnected villages across India. PMGSY roll-out followed a population-based rule (Asher and Novasad 2022; Garg et al. 2023). Villages with a household population greater than 1,000 were to be connected first, followed by villages with a population greater than 500, and only then villages with a population smaller than 500. Data on rural road construction comes from the Socioeconomic High-resolution Rural-Urban Geographic Dataset on India (SHRUG) (Asher et al. 2021). SHRUG provides detailed information on the timing of rural road construction under the PMGSY. We use SHRUG to identify the date of PMGSY road completion for each of the 30 VDSA villages. The population-based targeted road construction under PMGSY provides exogenous variation in market access to the VDSA villages.

Figure 1: Variation in PMGSY road construction across VDSA villages overtime



Notes: The data on village level earliest date of road construction comes from the Socioeconomic High-resolution Rural-Urban Geographic Dataset on India (SHRUG). The SHRUG database collates this data from the Government of India websites designed to report the progress of the program.

Figure 1 shows the proportion of villages connected or upgraded with PMGSY roads over the five-year period in our sample. Roughly 15 percent of the VDSA villages had roads upgraded or constructed under PMGSY before VDSA began in 2010. By 2014, this proportion had doubled to more than 30 percent. Overall, we observe a greater proportion of villages with upgraded roads than new roads.

(a) Summary statistics

Table 1 presents the mean and standard deviation of key variables. In around half of the month-year observations, households report having a large dairy animal with an average herd size of one. We find that the average monthly milk production to be 12 liters per household member, two-thirds of which is sold in the market. Almost all the milk sales are reported as sold locally within the village. The average monthly milk consumption is just 5 liters per household member, of which 57 percent is from home-produced milk, and the rest is from market purchases and informal transfers. Milk consumption from other sources, mainly informal transfers, forms a very small part of the total milk consumption.

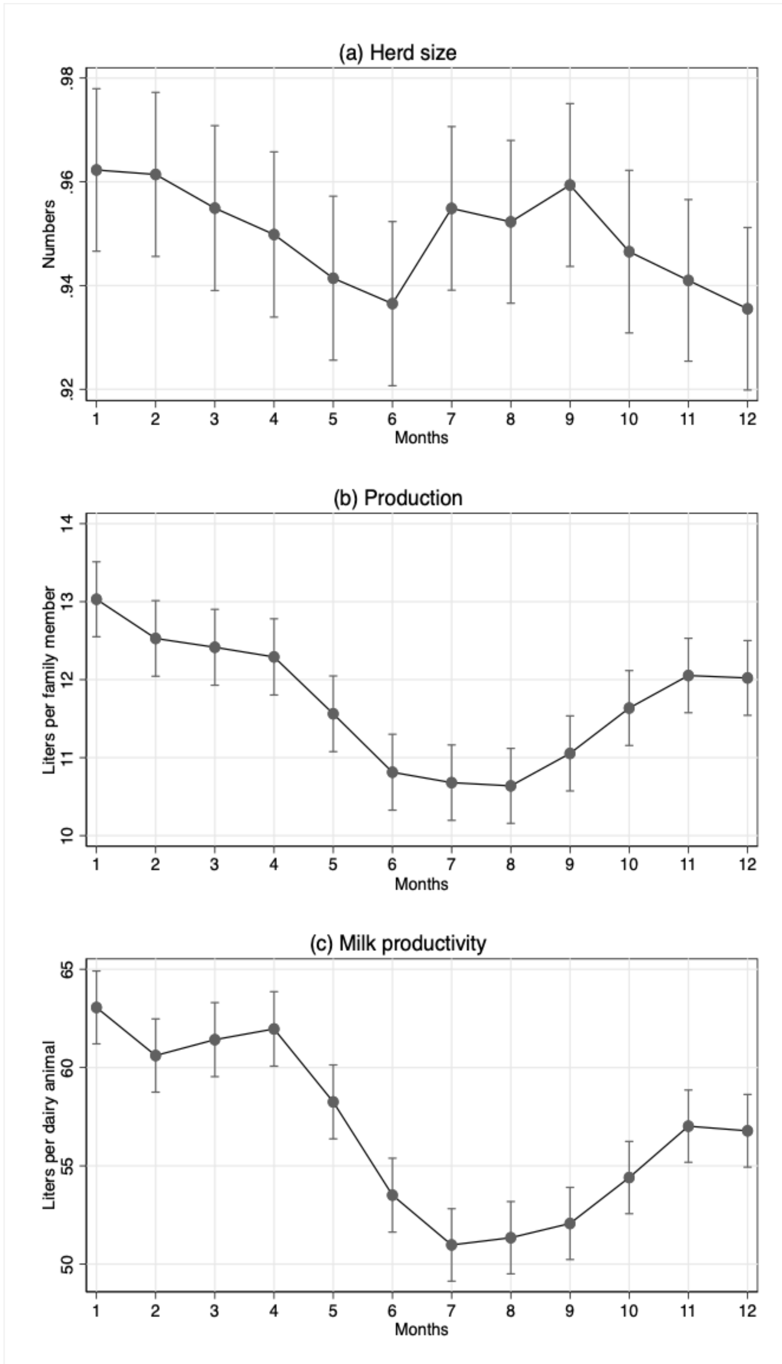
Consumption risk sharing is less critical from the point of view of food and nutrition security if most of the households report adequate milk consumption per capita. To check this, we compare reported consumption with the recommended milk consumption for the Indian population. The National Institute of Nutrition (NIN) of India recommends 300 milliliters of milk consumption per adult per day. This turns out to be 9 liters of monthly milk consumption per person. The average milk consumption reported in our data is just 55 percent of the NIN recommendations. Moreover, the reported milk consumption is less than the NIN's recommendations in 89 percent of household-month-year cases. Note that the averages presented in Table 1 only consider fluid milk consumption and do not account for other milk products consumed by the households. These are buttermilk, butter, ghee, and other milk preparations consumed by the households. Non-inclusion of these milk products consumed by the households could explain why we observe a difference of 1 liter per person between produced milk left after sales and home-produced milk consumed in Table 1. This can introduce measurement error in the dependent variable which can also be correlated with milk production. We will explicitly account for the consumption of other milk-based products in our estimation.

Table 1. Summary statistics

	(1)	(2)
Variables	Mean	SD
Dairy animal owning households	0.52	0.50
Herd size of large dairy animals (number)	0.95	1.33
Milk production (liter per person per month)	11.72	28.64
Milk sales (liter per person per month)	7.80	25.43
Milk consumption home-produced (liter per person per month)	2.88	4.92
Milk consumption purchased (liter per person per month)	2.02	2.89
Milk consumption informal transfers (liter per person per month)	0.08	0.64
Milk consumption total (liter per person per month)	4.98	4.55
Milk unit values/buy price (rupees per liter)	27.22	7.63
Milk sale price (rupees per liter)	24.75	7.18
Family members (number)	4.85	2.30
Consumption expenditure (rupees per person per month)	1722.92	4084.30

Figure 2 presents the monthly averages of herd size, milk production, and yield per animal across all households in our sample. These averages are estimated as marginal effects from regressions that control for household and year fixed effects. We observe some seasonal differences in average herd sizes, but it's mostly statistically insignificant. Milk production, however, shows a strong seasonal pattern. The average milk production is the highest in winter but starts going down from April onwards and is lowest in the summer/monsoon months of July and August. Panel (c) of the figure confirms that the seasonal pattern observed in milk production is almost entirely due to seasonal productivity shocks. Similar seasonal patterns in milk production and yields of large dairy animals for India are reported by Sirohi and Michaelowa (2007).

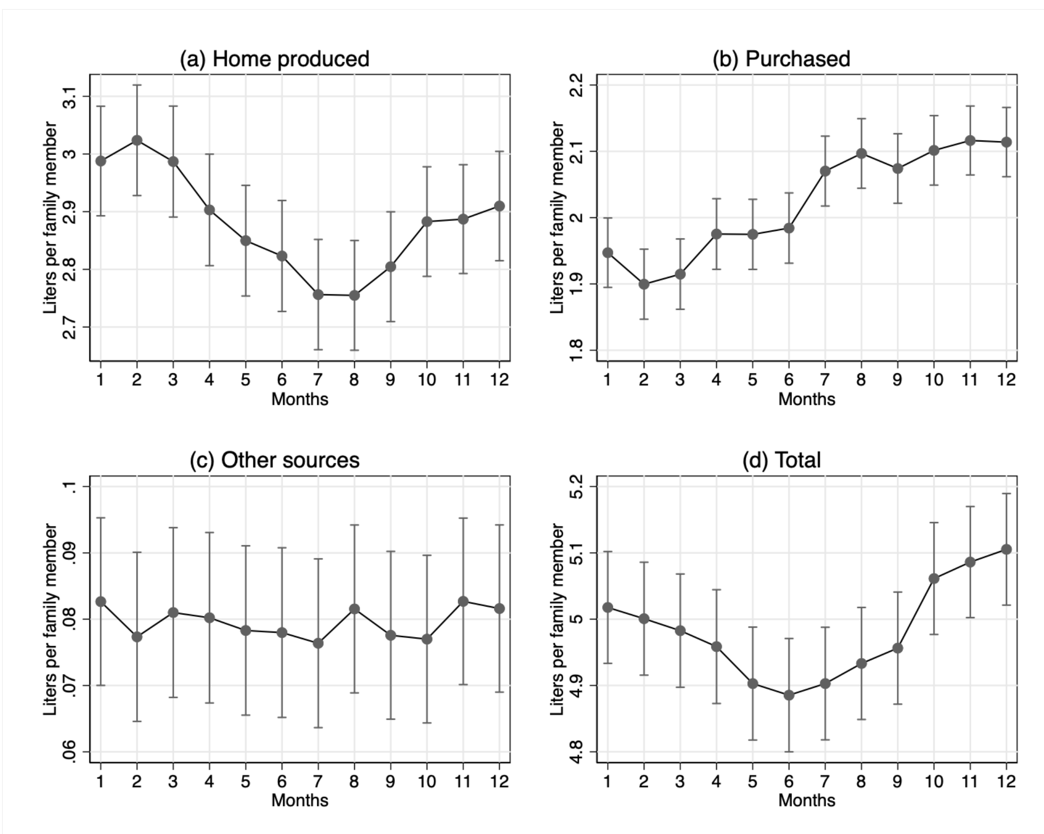
Figure 2. Seasonality in herd size, production and yield



Notes. The figure plots the herd size, production and milk productivity dairy per animal with 95% confidence intervals. Milk productivity is calculated as the total reported milk production divided by the total number of female cows and buffaloes. 96% of the reported milk production comes from cows and buffaloes. These averages are predicted from regression controlling for household and year-fixed effects.

Figure 3 shows the seasonal patterns in milk consumption by source. A seasonal pattern similar to production is also observed for home-produced milk consumption. Panel (b) shows that market purchases follow an opposite seasonal pattern to home-produced milk, higher in summer than in winter. But higher milk purchases are not enough to offset the decline in milk production in the summer months as average total consumption is also lower in summer. Figures 2 and 3 indicate strong seasonal patterns in the production and consumption of milk for these households. An empirical framework to test their effect on risk sharing and consumption smoothing is proposed in the next section.

Figure 3. Seasonality in milk consumption by source



Notes. The figure plots the average milk consumption per family member with 95% confidence intervals. These averages are predicted from regression controlling for household and year-fixed effects.

3. Empirical Framework

(a) Risk sharing test

An empirical test of the optimal risk-sharing hypothesis can be formulated as

$$c_{ivt} = \tau_{vt} + \beta y_{ivt} + \varepsilon_{ivt} \qquad (1)$$

where $c_{ivt} = \Delta \ln(C_{ivt})$, $y_{ivt} = \Delta \ln(Y_{ivt})$ and τ_{vt} are the village specific time fixed effects that control for the village level aggregate shocks. Since we are estimating (1) in first differences, the pareto weights drop out.[1] We add an error term for estimation. Under complete risk-sharing, conditional on village-level aggregate shocks captured by village-time fixed effects, $\beta = 0$; hence household consumption should be uncorrelated with household production.

(b) Preference shocks and measurement error

With preference shocks in the utility function, Pareto optimal consumption allocation will be determined by both village level aggregate and household level preference shocks (Mace 1991; Cochrane 1991; Townsend 1994; Chiappori et al. 2014). The monthly panel allows us to control for household specific preference shocks. Consider the following version of the test

$$c_{ivt} = \tau_{it} + m_{im} + \beta y_{ivt} + \varepsilon_{ivt} \qquad (2)$$

[1] See Appendix section (a) for the theoretical foundations of the optimal risk sharing test.

where τ_{it} and m_{im} denote household specific year and month fixed effects. Household specific time fixed effects allow us to control for annual preference shocks and household specific month fixed effects control for household level seasonal preference changes (see Appendix section (b) for details.).

A concern with the estimation of Equation (1) is that self-reported milk consumption and production would have measurement errors. Assuming that mismeasured values of consumption and production are defined as $C_{ivt} = C_{ivt}^{*}\theta_i^C u_{it}^C v_{im}^C$ and $Y_{ivt} = Y_{ivt}^{*}\theta_i^Y u_{it}^Y v_{im}^Y$, with household-specific (θ_i), household year specific (u_{it}) and household month specific (v_{im}) error components, Appendix section (b) shows that fixed effects in Equation (2) can also control for such errors.

This leaves the possibility that there are household-year-month specific measurement errors in production. Moreover, there can also be household-year-month specific preference shocks correlated with milk production. In both cases, the estimated β will have a bias. Generally, lagged variables have been used as instruments to correct the bias in risk-sharing parameter estimates due to measurement errors and omitted preference shocks (Dubois 2000). In our case, assuming that measurement errors in milk production are uncorrelated with measurement errors in the number of dairy animals, we can use lagged values of changes in the herd size of dairy animals as instruments. Note that changes in herd sizes would also have some measurement error but would likely be much less than self-reported milk production. Moreover, herd size data and milk production data are collected in different modules within the livestock module of the VDSA survey, further minimizing the likelihood of correlated measurement errors in the two estimates. In using the lagged changes in herd sizes as instruments, we also assume that herd size changes in the past months are uncorrelated with contemporaneous preference shocks.

(c) Social groups and risk sharing

Discussion in the previous section assumes village to be the appropriate social structure for risk sharing, but that may not be true. Evidence from the literature suggests that informal risk sharing networks form endogenously based on trust, kinship networks and affiliations to particular social groups within a village (Fafchamps 1992; Fafchamps and Lund 2003; De Weerdt and Dercon 2006; Kinnan and Townsend 2012). Moreover, Vanderpuye-Orgle and Barrett (2009) argue that socially invisible individuals not widely know in the community may get left out of social insurance networks.

While social invisibility may be hard to characterize in general, in the context of India, caste identity is an important factor influencing social network formation (Vanneman et al. 2006; Desai and Dubey 2011; Munshi and Rosenzweig 2016; Munshi 2019). Caste as an institution has evolved over 3,500 years in India, affiliation to which is inherited rather than chosen (Debnath and Jain 2020). Caste has a strong presence in every aspect of social, cultural and economic life in rural India and almost all social contracts and kinship networks span within the bounds of caste affiliations (Munshi 2019). Evidence suggests that caste affiliation may also impede the exchange of food across households belonging to different castes within communities (Marriott 2017; Raheja 1988; Béteille 2012; Munshi 2019). This implies that caste affiliations should be the more relevant group for testing risk sharing and social insurance (Munshi and Rosenzweig 2016; Mazzocco and Saini 2012).

With caste as the relevant social structure for risk sharing, the Pareto optimal allocation rule should equate individual consumption with aggregate resources of the caste based subpopulations rather than that of the entire village. Therefore, the appropriate risk sharing test specification is

$$c_{icvt} = \tau_{ct} + \beta y_{icvt} + \varepsilon_{icvt} \qquad (3)$$

where we replace village specific time fixed effects with caste group specific time fixed effects.

(d) Multiple commodities with non-separability

The canonical risk-sharing framework is based on a world with one composite commodity. Since we are interested in testing risk sharing in fluid milk, we have to consider the possibility of substitution across different commodities and its role in consumption smoothing in a single commodity.

Building on the standard model, consider the planner's problem in a two-commodity world. Suppose each household has now a preference over the two goods given by a utility function $U_i = U(C_{ivs}^Y, C_{ivs}^X)$ where C_{ivs}^Y and C_{ivs}^X are the amount of milk and crop consumed in state s.[2] The utility function is assumed to be non-separable in two commodities. As before, the optimal risk-sharing benchmark can be obtained by solving the social planner's allocation problem for this economy. The social planner maximizes a weighted sum of expected utilities: $\sum_{i=1}^{N} \lambda_i \sum_{s=1}^{S} \pi_s \, U(C_{ivs}^Y, C_{ivs}^X)$, subject to the aggregate village level resource constraints $\sum_{i=1}^{N} C_{ivs}^Y = \sum_{i=1}^{N} Y_{ivs} = W_{vs}^Y$ and $\sum_{i=1}^{N} C_{ivs}^X = \sum_{i=1}^{N} X_{ivs} = W_{vs}^X$ for the two commodities. As discussed in Townsend (1994), such optimization will lead to two first-order conditions, and non-separability will imply that the

[2] The utility function is assumed to be homothetic.

marginal utility of both commodities will have to be equated at the optimum. Therefore, aggregate endowments of both commodities will determine individual consumption allocations (Cochrane 1991; Townsend 1994). Consider the following variant of Equation (1)

$$c_{ivt} = \boldsymbol{\gamma}\boldsymbol{\mu}_{vt} + \beta y_{ivt} + \varepsilon_{iv} \qquad (4)$$

where $\boldsymbol{\mu}$ is a village level aggregate shocks of all commodities consumed by the household and $\boldsymbol{\gamma}$ is the vector of commodity specific parameters. Equation (4) allows for non-separability in the utility function by explicitly controlling for village level aggregate shocks of different commodities. The parameters in Equation (4) can be heterogenous based on households having different risk preferences (Kurosaki 2001; Schulhofer-Wohl 2011). Under that scenario, risk sharing test can be written as

$$c_{ivt} = \boldsymbol{\gamma_i}\boldsymbol{\mu}_{vt} + \beta y_{ivt} + \varepsilon_{iv} \qquad (5)$$

where now the parameter vector $\boldsymbol{\gamma_i}$ is household specific. Assuming a random coefficient structure of the form $\boldsymbol{\gamma_i} = \bar{\gamma} + \boldsymbol{u_i}$, Pesaran (2006) shows that a panel data regression in Equation (5) can be estimated using the following specification

$$c_{ivt} = \alpha_i + \beta_i y_{ivt} + \eta_i \bar{y}_{vt} + \sigma_i \bar{c}_{vt} + \varepsilon_{iv} \qquad (6)$$

For sufficiently large time dimensions, village level average production and consumption shocks denoted by $\bar{y}_{vt}$ and $\bar{c}_{vt}$ with heterogenous parameters approximate $\boldsymbol{\gamma_i}\boldsymbol{\mu}_{vt}$. Equation (6) is estimated by running a time series regression for each household with village level average production and consumption shocks as controls. Pesaran (2006) shows that under random coefficient structure, the mean of β's estimated from household level time series regressions gives a consistent estimate of the risk sharing parameter. This is known as the Common Correlated Effects Mean Group Estimator (CCEMG) and continues to be consistent under slope homogeneity and for any fixed number of unobserved common factors. Note that Equation (6) also allows for household specific heterogeneity in the risk-sharing parameter. Such heterogeneity may arise if complete risk sharing is rejected and the degree to which households can smooth consumption varies across households. The CCEMG estimator provides a consistent estimate of the mean of the parameter distribution.

(e) Imperfect risk sharing and channels of consumption smoothing

If optimal risk sharing is rejected, what are the different channels through which households smooth milk consumption? Storage is not a possibility due to high perishability of milk hence households can only rely on buying and selling in the local markets and informal transfers to smooth consumption. We follow the methodology proposed by Asdrubali et al. (1996) and Asdurbali et al. (2020) to quantify the contribution of different channels in consumption smoothing. Consider the following identity

$$C_{ivt} = Y_{ivt} + P_{ivt} - S_{ivt} + O_{ivt} \qquad (7)$$

where C_{ivt} is the milk consumption, Y_{ivt} is the milk production, P_{ivt} is the milk purchased locally, S_{ivt} is the quantity of milk sold, and finally O_{ivt} is the milk consumed from other sources. Other sources mainly include transfers of milk between households. We define two additional measures as: (1) $Y_{ivt}^{P} = Y_{ivt} + P_{ivt}$ which is the sum of milk produced and milk purchased from the market, and (2) $Y_{ivt}^{S} = Y_{ivt} + P_{ivt} - S_{ivt}$ which is milk production and purchases from the market net of milk sales. All quantities are expressed in per household member terms. Given these measures, household *i*'s per person milk production can be expressed as:

$$Y_{ivt} = \frac{Y_{ivt}}{Y_{ivt}^{P}} \times \frac{Y_{ivt}^{P}}{Y_{ivt}^{S}} \times \frac{Y_{ivt}^{S}}{C_{ivt}} \times C_{ivt} \qquad (8)$$

With some manipulation (see Appendix section (c) for details), Equation (8) can be expressed as the following identity.

$$\beta = 1 - \beta^{P} - \beta^{S} - \beta^{O} \qquad (9)$$

where the β on the LHS is the coefficient from Equation (1). Equation (9) expresses β as the residual after consumption smoothing achieved via purchases and sales of milk indicated by β^{P} and β^{S} respectively. β^{O} captures consumption smoothing achieved due to informal transfer across households. Given this structure, the null of autarky or no consumption smoothing is $\beta = 1$. If $\beta < 1$, then $(1 - \beta)$ can be interpreted as the degree of risk-sharing in the village (Asdurbali et al. 1996; Jalan and Ravallion 1999; Asdurbali et al. 2020). The β's on the RHS of Equation (9) can be estimated as coefficients from the following regressions.

$$y_{ivt} - y_{ivt}^{P} = \tau_{vt}^{P} + \beta^{P} y_{ivt} + \varepsilon_{ivt}^{P} \qquad (10)$$

$$y_{ivt}^{P} - y_{ivt}^{S} = \tau_{vt}^{S} + \beta^{S} y_{ivt} + \varepsilon_{ivt}^{S} \qquad (11)$$

$$y_{ivt}^{S} - y_{ivt}^{C} = \tau_{vt}^{O} + \beta^{O} y_{ivt} + \varepsilon_{ivt}^{O} \qquad (12)$$

Equations (10), (11), (12) and (1) define a system with the additive constraint on coefficients given in Equation (9). The parameters in this system of equations are assumed to be homogenous but can vary across households. For example, a household with a larger scale of production will more likely be selling milk than purchasing milk for home consumption. This implies that the channels through which larger farmers with surpluses and smaller farmers smooth consumption will be different. Moreover, reduced trade costs due to better road infrastructure will change households' incentives and interact with available surpluses and seasonality in complex ways. How these factors influence consumption smoothing is easily accommodated in our empirical structure. Consider the following characterization of the parameters in the system of equations outlined above.

$$\beta^j = \delta + \theta^H HS_i + \theta^R ROAD_{vt} + \theta^W WINTER_m + \gamma^{HR} HS_i \times ROAD_{vt} + \gamma^{HW} HS_i \times WINTER_m + \gamma^{HRW} HS_i \times ROAD_{vt} \times WINTER_m \quad (13)$$

where $j = \{P, S, O\}$, HS denotes the average herd size (time-invariant) of dairy animals during the entire period of the survey and captures the scale of production, $ROAD$ is a dummy variable that captures the village-level variation in road construction or upgradation under the PMGSY, and $WINTER$ is a dummy variable that takes values 1 for October, November, December, January, February, and March.

(f) Trade costs, seasonality, scale of production and prices

To capture the changes in incentives due to reduced trade costs, we look at the prices at which households buy and sell milk. The consumption module of the survey records the unit values of milk consumed and the production module records the prevailing price at which the milk will be sold. We use these monthly prices to see how seasonal production and access to new roads affect the buying and selling prices for these households.

Both the buy and sell price are conditional on households' market participation decisions, therefore, are endogenous and are a function of both observable and unobservable characteristics of the household. Moreover, unit values will depend on various factors including household preferences, type of milk, quality of milk and from where it was bought. Likewise, the self-reported sale price would also be a function of a variety of factors, including fat content, dairy animal species, etc. Consider the following empirical model for milk price differentials.

$$\ln\left(P_{ivmt}^{buy}\right) - \ln\left(P_{ivmt}^{sell}\right) = \alpha_i + m_{vm} + \tau_{vt} + \delta^{HR} HS_i \times ROAD_{vt} + \delta^{HW} HS_i \times WINTER_m + \delta^{RW} ROAD_{vt} \times WINTER_m + \delta^{HRW} HS_i \times ROAD_{vt} \times WINTER_m + \varepsilon_{ivmt} \qquad (14)$$

Where the dependent variable is the difference between the log of unit values and selling price of milk for household *i* in village *v* in month *m* and year *t*. We include household fixed effects to control for time-invariant factors that would influence the price differential. We also include village-specific month fixed effects to control for village-level seasonality in milk production and herd composition. Finally, village year-fixed effects are included to account for shocks and policy changes that can influence the price differential. Note that the sale price of milk is observed conditional on the milk being sold, and the decision to sell milk itself is a function of trade costs. The differential between unit values and sale price, therefore, would only be observed for the subsample of farmers selling milk. To avoid estimating Equation (14) on the subsample observed to be making a sale, we use the price reported by all milk-producing farmers in the production module as the sale price. This is the market price at which the farmers expect to sell milk in the market and is reported for all farmers reporting positive milk production. Equation (14) will be estimated individually with buying and selling prices as well as the price differential.

(g) Storage, financial transactions and anticipatory shocks

Although storage as a means to smooth consumption may not be a possibility in fluid milk, other commodities rural households produce and consume are storable. A priori, it's unclear how storage in other commodities would influence risk sharing in a non-storable commodity like milk. It is possible that with sufficient private stocks of other food items, shocks to milk consumption may not be of much consequence to the overall food security of the household. Or, consumption smoothing in milk may be of consequence conditional on food stocks of other important food commodities. To see how storage in other food commodities influences our estimate of β in Equation (1), we include annual stock changes of storable commodities as controls in our regressions.

We also empirically test the sensitivity of the estimates to transactions like borrowing, lending, savings, investments and asset sales households undertake for consumption smoothing. Likewise, anticipatory production shocks may lead to future production shocks influencing current consumption. We also test the importance of future and past production shocks on current milk consumption.

4. Results

(a) Risk-sharing, caste-based social structure, and preference shocks

Table 2 presents the estimates from the risk-sharing regressions. We start by presenting estimates from regressions with household fixed effects in column 1. In columns 2 and 3, we include year and month fixed effects to control for aggregate shocks and seasonality in milk production and consumption. In columns 4 we introduce village year fixed effects to control for village specific aggregate shocks and village month fixed effects to control for village specific seasonality. Finally, in column 5, we relax the assumption that aggregate year shocks and seasonality are independent and introduce village-month-year fixed effects. The complete risk-sharing hypothesis is clearly rejected for these households as we observe a positive and statistically significant association between consumption and production in all these specifications.

Table 2 also presents the seasonal differences based test in column 6. Specification 6 is our preferred empirical specification and provides exactly the same estimate of β as observed in levels with different versions of fixed effects. In specification 7, we test whether caste based social structure is the right risk-pooling group and introduce a caste-specific aggregate shock. Finally, to rule out the possibility that household specific preference shocks are leading to a correlation between consumption and production, we include household year and month fixed effects in the last specification (column 8). The magnitude and statistical significance of the coefficient on production are remarkably robust to different variants of the risk sharing test.

Table 2. Tests of risk-sharing

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Dependent variable: log milk consumption per person							
						Seasonally differenced		
y_{ivt}	0.211***	0.215***	0.215***	0.203***	0.201***			
	(0.024)	(0.026)	(0.026)	(0.025)	(0.026)			
$\Delta\ y_{ivt}$						0.200***	0.196***	0.205***
						(0.027)	(0.029)	(0.032)
Family members	-0.099***	-0.099***	-0.099***	-0.097***	-0.097***			
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)			
Log MPCE	0.216***	0.207***	0.209***	0.205***	0.210***			
	(0.027)	(0.028)	(0.028)	(0.024)	(0.024)			
Δ Family members						-0.101***	-0.103***	-0.115***
						(0.008)	(0.008)	(0.009)
Δ Log MPCE						0.207***	0.201***	0.155***
						(0.033)	(0.024)	(0.027)
Household FE	Yes	Yes	Yes	Yes	Yes	No	No	No
Month FE	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	Yes	Yes	Yes	Yes	No	No	No
Village×Month FE	No	No	No	Yes	No	No	No	No
Village×Year FE	No	No	No	Yes	No	No	No	No
Household×Month FE	No	No	No	No	No	No	No	Yes
Household×Year FE	No	No	No	No	No	No	No	Yes
Village×Month×Year	No	No	No	No	Yes	No	No	No
Caste×Village×Month×Year	No	No	No	No	No	No	Yes	No
N	61420	61420	61420	61420	61420	45578	45180	44020
R^2	0.74	0.75	0.75	0.78	0.80	0.23	0.42	0.58
F	191.46	162.31	160.31	172.73	171.81	176.82	144.96	203.44

Notes: y_{ivt} and $\Delta\ y_{ivt}$ denote log per person household milk production in its seasonal difference respectively. The dependent variable in the last specification is seasonally differenced log milk consumption per person. MPCE denotes the monthly per person value of consumption expenditure. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 3. Aggregate shocks to other commodities and risk sharing

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable: seasonally differenced log milk consumption per person							CCEMG
$\Delta\, y_{ivt}$	0.194***	0.192***	0.193***	0.192***	0.192***	0.191***	0.224***
	(0.027)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.069)
Village average Δ log milk expenditure per member	0.702***	0.710***	0.729***	0.731***	0.731***	0.729***	
	(0.047)	(0.056)	(0.054)	(0.053)	(0.055)	(0.054)	
Village average Δ log cereals expenditure per member		-0.059	-0.019	-0.011	-0.013	-0.009	
		(0.072)	(0.070)	(0.070)	(0.070)	(0.068)	
Village average Δ log pulses expenditure per member		-0.033	-0.030	-0.021	-0.025	-0.034	
		(0.040)	(0.039)	(0.040)	(0.037)	(0.036)	
Village average Δ log vegetables expenditure per member			-0.065***	-0.063***	-0.058**	-0.056**	
			(0.023)	(0.022)	(0.022)	(0.022)	
Village average Δ log fruits expenditure fruits per member			-0.016	-0.013	-0.010	-0.009	
			(0.011)	(0.012)	(0.012)	(0.012)	
Village average Δ log meat eggs & fish expenditure per member				-0.020**	-0.017*	-0.016*	
				(0.009)	(0.009)	(0.009)	
Village average Δ log oils expenditure per member				-0.017	-0.016	-0.008	
				(0.030)	(0.029)	(0.029)	
Village average Δ log sugar expenditure per member				-0.023	-0.019	-0.017	
				(0.045)	(0.046)	(0.045)	
Village average Δ log beverages expenditure per member					-0.002	-0.001	
					(0.014)	(0.014)	
Village average Δ log processed foods expenditure per member					-0.012	-0.006	
					(0.014)	(0.014)	
Village average Δ log other foods expenditure per member					-0.014	-0.009	
					(0.026)	(0.028)	
Village average Δ log non food expenditure per member						-0.043*	
						(0.023)	
N	44759	44759	44759	44759	44759	44759	

Notes: All regressions include the change in household size and change in log per member value of consumption as control variables. $\Delta\, y_{ivt}$ denotes seasonally differenced log per person household production of milk. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. CCEMG denotes estimates from the Common Correlated Effects Mean Group Estimator. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

(b) Multiple commodities

As discussed in section 3, relaxing the composite good assumption and separability in the utility function means that aggregate shocks of all commodities in a household's utility function would determine the optimal milk consumption allocation. Although village or caste specific time fixed effects would control for all types of aggregate shocks, including aggregate shocks to other commodities, it is still useful to see whether village consumption of other food commodities correlates with the household's milk consumption.

Table 3 presents the estimates of risk-sharing tests, including village-level aggregate consumption expenditures of other commodity groups consumed by households in our data. Note that, though we consider the physical quantity of milk consumption and production, the aggregate shocks to other commodities are in value terms for two reasons. First, it makes more sense to aggregate commodities into groups based on value rather than quantities. Second, using expenditures also implies that we can account for price based variation in these commodities.

Comparing specifications 1 to 6, we observe that the estimates of β remain comparable to our estimates in Table 2. In general, village-level expenditure on vegetables and meat, fish, and eggs, and non-food items show a negative and statistically significant correlation with milk consumption. The last specification in the table presents the estimates from the CCEMG estimator, which accounts for the possibility that the coefficients on the aggregate shocks are heterogeneous across these households. Such a possibility arises if risk preferences vary across households. Under optimal allocation, once consumption insurance to idiosyncratic shocks is achieved via risk pooling, households with lower risk aversion would bear greater aggregate risk than more riskaverse households (Schulhofer-Wohl 2011). This implies that the coefficient on aggregate shocks would vary across households based on their risk preferences and the curvature of the utility function. The omission of this heterogeneity has been shown to bias the estimates of the risk sharing parameter. Allowing for heterogeneity in the aggregate shocks, however, does not seem to influence our estimates much (Table 3 specification 7).

(c) Degree of consumption smoothing

Table 4 presents the estimates for β's from Equations (10) to (12) estimated as a system with a constraint on the coefficients defined in Equation (9). The estimates in columns 1 to 4 represent consumption smoothing achieved from milk purchases, sales, and other sources, respectively. The estimate in the last column is residual and is the same as the one reported in column 6 of Table 2. We first test the null of no consumption smoothing or $\beta = 1$, which is rejected (hypothesis 1 in Table 4). We find that, on average, household milk consumption is insured from around 80 percent of the shocks to milk production ($1 - \beta = 0.80$).

Looking at columns 1 and 2 of the table, we observe that two-thirds of the shocks to milk production are smoothed by the purchase and sales of milk in the local market. In terms of magnitude, market purchases account for almost half of the consumption smoothing achieved in these villages, followed by milk sales which account for another 36 percent of the total consumption smoothing. In total, sales and purchases account for 83 percent of the total consumption smoothing by these households. Informal transfers account for less only 17 percent of the total consumption smoothing.

Table 4. Channels of risk-sharing

	(1)	(2)	(3)	(4)
Proportion of production shocks smoothed out by	Purchases	Sales	Transfers	Residual
	β^P	β^S	β^O	β
	0.380***	0.287***	0.133***	0.200***
	(0.022)	(0.046)	(0.038)	(0.027)
1. $H^0: 1 - \beta = 0$	0.800***			
	(0.027)			
2. $H^0: \beta^P - \beta^S = 0$	0.093			
	(0.057)			
3. $H^0: \beta^P - \beta^O = 0$	0.248***			
	(0.048)			
4. $H^0: \beta^S - \beta^O = 0$	0.155**			
	(0.076)			
N	45578			

Notes: All regressions include the change in household size and change in log per members value of consumption as control variables. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Although market transactions seem to provide the highest degree of consumption smoothing, we also test whether these estimates are statistically different. We are unable to reject the null that consumption smoothing achieved from sales or purchases of milk from the market are equal (hypothesis 2 in Table 4). We, however, reject the null that the degree of consumption smoothing achieved from milk purchase and sales is equal to that achieved from informal transfers (hypotheses 3 and 4 in Table 4). Overall, we find that market transactions dominate informal transfers as a channel of consumption smoothing.

To check whether the omission of consumption of other milk products leads to biased estimates, we include changes in per-person consumption of buttermilk, butter, ghee, and other milk preparations consumed by the households as covariates in our regressions. Appendix Table

A1 shows that our estimates are robust to the inclusion of these covariates. We also test whether our estimates are robust to other types of measurement errors as mentioned in section 3(b). Table A2 in the appendix presents the instrumental variable estimates of the risk-sharing coefficients where the instruments are lagged herd sizes. These estimates are comparable to the estimates in Table 4.

(d) Seasonality, scale of production, roads and consumption smoothing

How does consumption smoothing via different channels vary with the scale of production and road access? Table 5 shows that households with larger average herd sizes rely more on sales for consumption smoothing than purchases. This is intuitive as for larger dairy farmers, periods of surplus milk will be more likely than deficit. In winter, larger dairy farmers divert the seasonal surplus milk to informal transfers. This is evident in the positive and statistically significant triple interaction between production shocks, average herd size, and the winter dummy in the case of informal transfers (Table 5 specification 3). We also find evidence that improvement in quality and access to roads leads to greater consumption smoothing via milk sales, which does not seem to compete with consumption smoothing from other channels.

Table 5. Scale of production, roads, seasonality and channels of risk-sharing

	(1)	(2)	(3)	(4)
	β^P	β^S	β^O	β
$\Delta\, y_{ivt}$	0.491***	0.209***	0.099**	0.201***
	(0.036)	(0.058)	(0.042)	(0.037)
$\Delta\, y_{ivt} \times HS$	-0.064***	0.046***	0.029	-0.011
	(0.012)	(0.017)	(0.021)	(0.010)
$\Delta\, y_{ivt} \times ROAD$	-0.039	0.042	-0.061	0.058
	(0.055)	(0.083)	(0.057)	(0.066)
$\Delta\, y_{ivt} \times WINTER$	0.004	0.005	-0.017	0.008
	(0.010)	(0.014)	(0.013)	(0.015)

$\Delta\, y_{ivt} \times HS \times ROAD$	-0.026	0.033*	0.015	-0.023
	(0.022)	(0.019)	(0.028)	(0.015)
$\Delta\, y_{ivt} \times HS \times WINTER$	-0.015**	-0.007	0.026**	-0.004
	(0.007)	(0.011)	(0.012)	(0.008)
$\Delta\, y_{ivt} \times HS \times ROAD \times WINTER$	0.001	-0.013	-0.016	0.028
	(0.013)	(0.018)	(0.011)	(0.029)
N	45578			

Notes: All regressions include the change in household size and change in log per member value of consumption as control variables. $\Delta\, y_{ivt}$ denotes seasonally differenced log per person household production of milk. HS is the average herd size of a farm household during the entire period. ROAD captures rural road construction or upgrades under the PMGSY. WINTER is a dummy variable that takes values 1 for October, November, December, January, February, and March. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

We do not observe strong effects of reduced trade costs due to PMGSY roads in Table 5. This could be because we club upgradation and new road construction into one variable. To see whether new roads have a stronger effect on channels of consumption smoothing, we present the estimates considering only new roads constructed under PMGSY in Table 6. We indeed find that new roads have stronger effects on consumption smoothing. As before, we observe that larger farmers rely more on sales to smooth consumption than smaller farmers, and new roads enhance this reliance. An interesting finding is that reduced trade costs and access to distant markets compete with informal transfers and social insurance as a means to smooth consumption. In terms of magnitude, new roads completely offset the increased consumption smoothing via informal transfers by large farmers in the winter season (Table 6 specification 3).[3] Estimates from an alternative specification with linear and all possible interactions of herd size (*HS*), winter season

[3] These findings are robust to inclusion of interactions with upgraded roads.

($WINTER$) and a dummy variable for new roads constructed under the PMGSY ($NROAD$) are presented in Appendix Table A3.

Table 6. Scale of production, new roads, seasonality and channels of risk-sharing

	(1)	(2)	(3)	(4)
	β^P	β^S	β^O	β
$\Delta\, y_{ivt}$	0.477***	0.210***	0.088**	0.225***
	(0.033)	(0.055)	(0.038)	(0.039)
$\Delta\, y_{ivt} \times HS$	-0.063***	0.052***	0.028	-0.018*
	(0.010)	(0.015)	(0.018)	(0.010)
$\Delta\, y_{ivt} \times NROAD$	0.039	0.058	-0.045	-0.051
	(0.041)	(0.065)	(0.058)	(0.042)
$\Delta\, y_{ivt} \times WINTER$	0.003	0.006	-0.016	0.007
	(0.010)	(0.014)	(0.012)	(0.014)
$\Delta\, y_{ivt} \times HS \times NROAD$	-0.065***	0.028*	0.042	-0.005
	(0.015)	(0.017)	(0.027)	(0.022)
$\Delta\, y_{ivt} \times HS \times WINTER$	-0.014**	-0.008	0.025**	-0.003
	(0.006)	(0.010)	(0.010)	(0.007)
$\Delta\, y_{ivt} \times HS \times NROAD \times WINTER$	-0.009	-0.013	-0.029***	0.051
	(0.020)	(0.031)	(0.010)	(0.051)
N	45578			

Notes: All regressions include the change in household size and change in log of per member value of consumption as control variables. $\Delta\, y_{ivt}$ denotes seasonally differenced log per person household production of milk. HS is the average herd size of a farm household during the entire period. NROAD captures new rural road construction under the PMGSY. WINTER is a dummy variable that takes values 1 for October, November, December, January, February, and March. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Although road construction under the PMGSY was targeted based on the baseline village population, it's possible that new roads crowded in other complementary infrastructure in these villages. It's also possible that PMGSY roads coincided with other developmental or policy changes in the VDSA villages. If this is true, then the results in Table 6 can be driven by other correlated village-level changes. Our key interest is in testing whether the finding that roads offset consumption smoothing via informal transfers is robust to inclusion of village-year fixed, which would wipe out all correlated village-level changes over the survey period (see Appendix Table A5). Appendix Tables A4 and A5 show that the findings in Table 6 are robust to controlling for other unobserved village-level trends correlated with road construction.

We also explore whether the scale of production, seasonality, and access to new roads have different implications for consumption smoothing via sales to formal and informal channels (Table A6). We define formal channels as sales to cooperatives and private processors. Informal channels include sales to local agents, shops, and fellow farmers. 78 percent of the total milk sales are made to formal sources and only 22 percent are made to informal sources. Table A4 shows that new roads enhance the contribution of sales to formal channels in consumption smoothing, especially for farmers with a larger scale of production. This seems to happen at the cost of lower consumption smoothing from milk sales to informal channels.

(e) Seasonality, scale of production, new roads and dairy processing capacity

The VDSA states vary a lot in terms of the structure of the dairy value chains. For example, Gujarat and Karnataka have a high presence of dairy cooperatives. In comparison, Maharashtra has a higher private processor presence. The Eastern states of Bihar, Jharkhand and Odisha have less developed milk value chains and most of the milk sales are made to the informal sector. Although these differences in milk value chains are structural and are observed at the baseline, it's possible that the construction of new roads is correlated with the expansion of dairy processing capacity in these states. Village-level data on milk processing plants for the survey period is unavailable, but state-level data on the number of milk processing plants is available from the

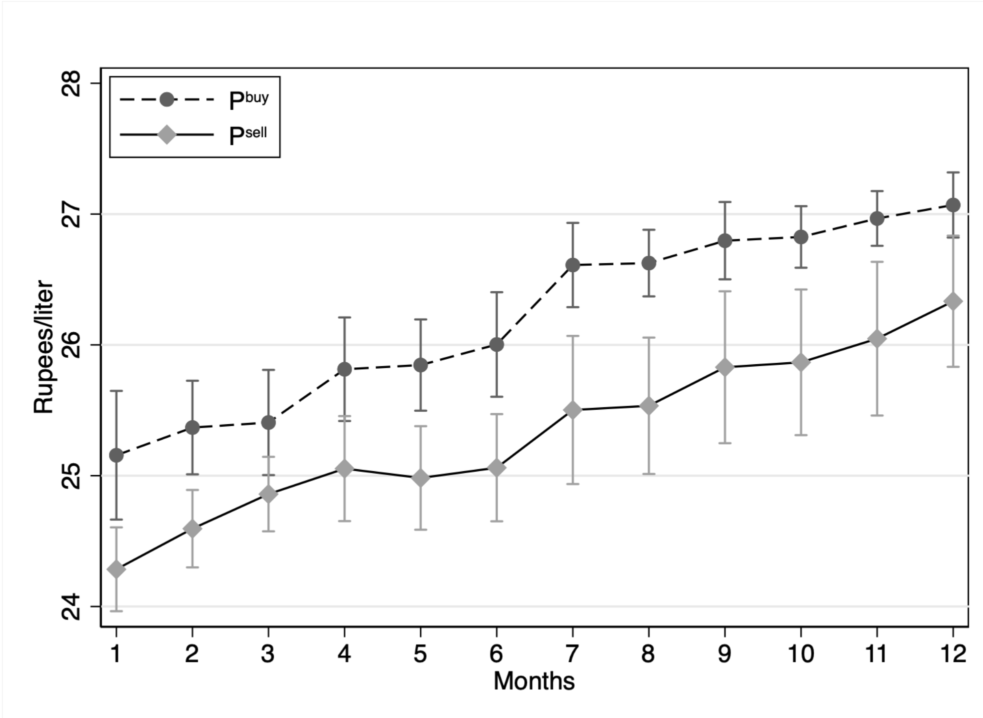
Annual Survey of Industries. We use this data to see whether village-level road construction correlates with state-level milk processing capacity changes. Appendix Table A7 shows that milk processing capacity is uncorrelated with road expansion under the PMGSY.

Appendix Table A8 presents the estimates of Equation (15) where we replace the PMGSY roads dummy with the log of number of milk processing plants (*PPLANT*) at the state level. While we believe changes in the number of milk processing plants would be correlated with other state-level changes, it is still interesting to see how consumption smoothing via different channels varies with milk processing capacity. We observe that a higher number of milk processing plants is associated with greater consumption smoothing via milk sales and lower consumption smoothing from informal transfers. These patterns seem to be stronger for larger farmers. Like with the case of PMGSY roads, we observe greater consumption smoothing via informal transfers for larger farmers in the winter season, but greater milk processing capacity seems to offset this effect.

(f) Seasonality, scale of production, new roads and prices

An important result in the previous section is that access to new roads leads to surplus producing farmers relying more on sales for consumption smoothing. Roads also seem to reduce the role of informal transfers in consumption smoothing. In this section, we see whether incentives in the form of the prices at which milk is bought and sold are influenced by reduced trade costs in the form of access to new roads.

Figure 4. Monthly average buy and sell price of milk for dairy animal owning households



Notes. The figure plots the average buy and sell price of milk for households reporting owning at least one dairy animal during the period of the survey with 95% confidence intervals. These averages are predicted from regression controlling for household and year-fixed effects.

Figure 4 shows the well-known feature of agricultural households that the price at which a commodity is purchased is generally higher than the price at which the commodity will be sold. This price band is due to frictions like trade costs (de Janvry et al. 1991; Barret 2008). Note that Figure 4 shows average prices conditional on household and year fixed effects hence time invariant quality differences cannot explain the statistically significant differences in the two prices for most of the months. Moreover, we also observe seasonal differences in milk prices.

Table 7. Scale of production, new roads, seasonality and prices

	(1)	(2)	(3)
	$\ln(P^{buy})$	$\ln(P^{sell})$	$\ln(P^{buy}) - \ln(P^{sell})$
$HS \times WINTER$	-0.002	-0.000	-0.000
	(0.002)	(0.001)	(0.001)
$HS \times NROAD$	-0.017**	0.020***	-0.008**

	(0.007)	(0.003)	(0.004)
$NROAD \times WINTER$	-0.018	-0.034***	0.010
	(0.023)	(0.005)	(0.015)
$HS \times NROAD \times WINTER$	0.006	0.004*	0.005
	(0.015)	(0.002)	(0.008)
Log MPCE	0.011**	0.013***	0.001
	(0.004)	(0.004)	(0.003)
Family members	0.001	0.002	0.012
	(0.009)	(0.016)	(0.008)
Herd size	0.003	0.019*	-0.003*
	(0.004)	(0.011)	(0.001)
R^2	0.790	0.840	0.436
N	40441	25339	25339

Notes: All regressions include household fixed effects, village month fixed effects and village year fixed. HS is the average herd size of a farm household during the entire period. NROAD captures new rural road construction under the PMGSY. WINTER is a dummy variable that takes values 1 for October, November, December, January, February, and March. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 7 presents the estimates of Equation (14) for unit values, sale price and the price differential on households which report owning at least one dairy animal during the entire period of the survey. These regressions also include the log of total consumption value per person as a control. On average, new roads lead to a reduction in the price at which farm households purchase milk and an increase in the price at which they expect to sell milk. These effects are stronger for farmers with larger herds. We also observe some seasonal variation in the effect of new roads on sale prices. Finally, in column 3, we observe that new roads lead to a narrower price band between buy and sell prices for milk-producing households.

(g) Storage, financial transactions and risk sharing

Although fluid milk is not storable, rural households do maintain stock of other storable food commodities with the objective of future sales and consumption smoothing. Households also maintain stocks of foodgrains as seeds or as animal feed. If in periods of an adverse milk production shock, households use pre-existing stocks of food items to smooth their total food consumption, then it's possible that milk consumption may show extra sensitivity to production shocks (Ábrahám and Laczó 2018). If this is true, then changes in stocks are omitted variables in our empirical specification and their inclusion as covariates in Equation 1 should lead to a reduction in the correlation between milk consumption and production. We, however, do not see evidence of changes in stocks of other commodities having an influence on the risk-sharing parameter (Appendix Table A9). Moreover, changes in stocks of cereals and pulses are uncorrelated with milk consumption. We also include changes in the value of total stocks, which included food grains, seeds, animal feed, and other commodities but find it to be uncorrelated with milk consumption (Appendix Table A9 Specification 3).

Rural households also rely on savings and dis-savings, sale and purchase of assets, and credit for consumption smoothing. Such transactions can also be used to smooth a single component of food consumption and should be included as covariates in the risk-sharing regression. Appendix Table A10 presents the estimates of the risk-sharing parameter with controls for households' monthly financial transactions reported in the VDSA data. The magnitude and statistical significance of the risk-sharing parameter hardly change with the inclusion of different financial transactions undertaken by the households during the survey period (Appendix Table A10).

One final concern with the estimates of the risk-sharing parameter is that we only capture the instantaneous correlation between consumption and production. Future shocks to milk production may influence current milk consumption if such shocks are anticipated by the households. Likewise, past shocks may also influence current consumption. While the planner's allocation in the canonical risk-sharing model rules out lagged and lead effects of idiosyncratic production shocks, a failure of complete risk-sharing opens up such a possibility. Appendix Figure A2 presents the estimates of 12 months lagged and lead effects of production shocks on current milk consumption. As expected, only the instantaneous production shock shows the highest correlation with current milk consumption and all other estimates are close to zero.

5. Conclusion

In this paper, we study risk sharing and consumption smoothing in fluid milk for dairying households in rural India. This application is unique as, unlike most of the literature studying consumption risk sharing assuming a composite commodity, we test risk sharing in a single, highly perishable and non-storable commodity. While our emphasis is on uncovering the different channels through which rural producer-consumer households insulate consumption from supply fluctuations in fluid milk, we do that within the conventional framework of the complete risk-sharing hypothesis.

The complete risk-sharing hypothesis is rejected for households in our sample but we observe a high degree of consumption insurance. Moreover, buying and selling from the market turns out to be the dominant channel through which this high degree of insurance is achieved. The degree of insurance provided by informal transfers is much smaller in magnitude. We also observe seasonal differences in our estimates. Given the overall greater supply of fluid milk in the winter season, we find that larger surplus-producing households rely more on milk sales and informal transfers for consumption smoothing in the winter months. The availability of newer roads, however, reduces consumption smoothing via informal transfers for surplus producing farmers in the winter season.

It is important to see these findings from the aspect of production risks faced by agricultural households in developing countries. Unlike the large body of evidence on the role of informal insurance, our findings show that market transactions play a dominant role in consumption smoothing in fluid milk. Lower trade frictions in the form of access to better road infrastructure reduce the role of informal transfers without any impact on overall consumption insurance. This indicates that markets can easily take up the role of insulating consumption from production shocks in this particular case. This finding has special relevance if future changes in climate would make local weather more unpredictable and agricultural production more volatile. Local commodity markets can then act as the medium through which consumption can be insulated from most of the increased production volatility.

While this paper focuses on a single commodity, these findings open a wider research agenda of exploring the relative role of different channels of consumption smoothing in the commodities produced by rural agricultural households. Given the differences in commodities based on perishability, storability, and the development of local commodity markets, the role of different channels of consumption smoothing will also differ. Investigating such differences across commodities will be important to understand how households mitigate the welfare consequences of commodity-specific production risks.

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Appendix

(a) Canonical risk sharing model

For illustration purposes, we start with the canonical risk-sharing framework. We later discuss variants that relax some of the assumptions in this basic framework. Consider *N* agents living within a village. Each agent *i* in village *v* has a stochastic endowment of a commodity Y_{ivs}, the realization of which is based on different but finite states of the world *s*. Each state occurs with an exogenous probability π_s with $\sum_{s=1}^{S} \pi_s = 1$. Each agent i has a continuous, monotonically increasing, concave, and twice differentiable utility function $U_i = U(C_{ivs})$, where C_{ivs} is the amount consumed of the good in state s. Each agent's expected utility is thus $\sum_{s=1}^{S} \pi_s U(C_{ivs})$.

The optimal risk-sharing benchmark can be obtained by solving the social planner's allocation problem for this economy. The social planner maximizes a weighted sum of expected utilities: $\sum_{i=1}^{N} \lambda_i \sum_{s=1}^{S} \pi_s U(C_{ivs})$, where λ_i are the Pareto weights, subject to the aggregate village level resource constraint $\sum_{i=1}^{N} C_{ivs} = \sum_{i=1}^{N} Y_{ivs} = W_{vs}$. The first-order condition for an agent *i* is

$$\lambda_i \pi_s U'(C_{ivs}) = \mu_{vs} \qquad \text{(A1)}$$

where μ_{vs} is the Lagrange multiplier on the aggregate resource constraint. The first-order condition implies that each agent's marginal utility will only depend on the village level aggregate resources and will be independent of individual endowments. Assuming a CRRA utility function, $\frac{C^{1-\gamma}}{1-\gamma}$, Equation (A1) can then be expressed as

$$\ln(C_{ivt}) = \frac{1}{\gamma}\ln\lambda_i - \frac{1}{\gamma}\ln\left(\frac{\mu_{vt}}{\pi_t}\right) \qquad \text{(A2)}$$

where *s* is replaced with *t* indicating time periods and γ is the coefficient of relative risk aversion.

(b) Risk sharing test with preference shocks and measurement error in dependent and independent variables

Assume that the utility function is given as

$$U(C_{ivt}) = b_{it}\frac{C_{ivt}^{1-\gamma}}{1-\gamma} \qquad \text{(B1)}$$

where b_{it} are preference shocks. The first-order condition can be written as

$$C_{ivt} = \left(\frac{1}{\lambda_i}\right)^{-\frac{1}{\gamma}}\left(\frac{1}{b_{it}}\right)^{-\frac{1}{\gamma}}\left(\frac{\mu_{vt}}{\pi_t}\right)^{-\frac{1}{\gamma}} \qquad \text{(B2)}$$

Based on the first order condition in Equation (B2), consider the following version of the risk-sharing test

$$C_{ivt} = \lambda_i^{\frac{1}{\gamma}} b_{it}^{\frac{1}{\gamma}}\left(\frac{\mu_{vt}}{\pi_t}\right)^{-\frac{1}{\gamma}} Y_{ivt}^{\beta} \qquad \text{(B3)}$$

where we have added production as multiplicative to the RHS of the first-order condition. For risk sharing to be complete, therefore, $\beta = 0$. Assume preference shocks to have the following multiplicative form

$$b_{it} = \sigma_i\phi_{it}\omega_{im} \qquad \text{(B4)}$$

where b_{it} has a household specific component (σ_i), household year specific trends (ϕ_{it}) and seasonal preference changes (ω_{im}). Moreover, consumption and production are measured with errors in the following manner.

$$C_{ivt} = C^*_{ivt}\theta^C_i u^C_{it} v^C_{im} \qquad \text{(B5)}$$

$$Y_{ivt} = Y^*_{ivt}\theta^Y_i u^Y_{it} v^Y_{im} \qquad \text{(B6)}$$

Equations B5 and B6 model the measurement errors as multiplicative, with both variables having a household-specific error (θ_i), a household-year-specific error (u_{it}), and a household-month-specific error (v_{im}) in measurement. Substituting B4, B5 and B6 in B3, we get

$$C^*_{ivt}\theta^C_i u^C_{it} v^C_{im} = \lambda_i^{\frac{1}{\gamma}}(\sigma_i\phi_{it}\omega_{im})^{\frac{1}{\gamma}}\left(\frac{\mu_{vt}}{\pi_t}\right)^{-\frac{1}{\gamma}}(Y^*_{ivt}\theta^Y_i u^Y_{it} v^Y_{im})^{\beta} \qquad \text{(B7)}$$

Taking logs on both sides and simplifying, we get

$$\ln(C^*_{ivt}) = \alpha_i + t_{it} + \vartheta_{im} + \beta\ln(Y^*_{ivt}) + \varepsilon_{ivt} \qquad \text{(B8)}$$

With the $\alpha_i = \frac{1}{\gamma}\ln\lambda_i + \frac{1}{\gamma}\ln\sigma_i + \beta\ln\theta^Y_i - \ln\theta^C_i$, $t_{it} = -\frac{1}{\gamma}\ln\left(\frac{\mu_{vt}}{\pi_t}\right) + \frac{1}{\gamma}\ln\phi_{it} + \beta\ln u^Y_{it} - \ln u^C_{it}$ and $\vartheta_{im} = \frac{1}{\gamma}\ln\omega_{im} + \beta\ln v^Y_{im} - \ln v^C_{im}$. Taking first difference of Equation (B8) leads to a fixed effects regression of the form in Equation (2).

(c) Production variance decomposition

To decompose production variance, we take logs and first difference of Equation (8) on both sides to get

$$\Delta\text{Ln}(Y_{ivt}) = \Delta\text{Ln}(Y_{ivt}) - \Delta\text{Ln}(Y_{ivt}^{P}) + \Delta\text{Ln}(Y_{ivt}^{P}) - \Delta\text{Ln}\left(Y_{ivt}^{S}\right) + \Delta\text{Ln}\left(Y_{ivt}^{S}\right) - \Delta\text{Ln}(C_{ivt}) + \Delta\text{Ln}(C_{ivt}) \qquad \text{(C1)}$$

Multiplying by $\Delta\text{Ln}(Y_{ivt})$ on both sides and taking expectations

$$\begin{aligned}
\text{Var}\big(\Delta\text{Ln}(Y_{ivt})\big) &= \text{Cov}\left(\Delta\text{Ln}(Y_{ivt}) - \Delta\text{Ln}(Y_{ivt}^{P}), \Delta\text{Ln}(Y_{ivt})\right) \\
&+ \text{Cov}\left(\Delta\text{Ln}(Y_{ivt}^{P}) - \Delta\text{Ln}\left(Y_{ivt}^{S}\right), \Delta\text{Ln}(Y_{ivt})\right) \\
&+ \text{Cov}\left(\Delta\text{Ln}\left(Y_{ivt}^{S}\right) - \Delta\text{Ln}(C_{ivt}), \Delta\text{Ln}(Y_{ivt})\right) \\
&+ \text{Cov}\big(\Delta\text{Ln}(C_{ivt}), \Delta\text{Ln}(Y_{ivt})\big) \qquad \text{(C2)}
\end{aligned}$$

Dividing by $\text{Var}\big(\Delta\text{Ln}(Y_{ivt})\big)$ on both sides we get

$$\begin{aligned}
1 &= \frac{\text{Cov}\left(\Delta\text{Ln}(Y_{ivt}) - \Delta\text{Ln}(Y_{ivt}^{P}), \Delta\text{Ln}(Y_{ivt})\right)}{\text{Var}\big(\Delta\text{Ln}(Y_{ivt})\big)} + \frac{\text{Cov}\left(\Delta\text{Ln}(Y_{ivt}^{P}) - \Delta\text{Ln}\left(Y_{ivt}^{S}\right), \Delta\text{Ln}(Y_{ivt})\right)}{\text{Var}\big(\Delta\text{Ln}(Y_{ivt})\big)} \\
&+ \frac{\text{Cov}\left(\Delta\text{Ln}\left(Y_{ivt}^{S}\right) - \Delta\text{Ln}(C_{ivt}), \Delta\text{Ln}(Y_{ivt})\right)}{\text{Var}\big(\Delta\text{Ln}(Y_{ivt})\big)} \\
&+ \frac{\text{Cov}\big(\Delta\text{Ln}(C_{ivt}), \Delta\text{Ln}(Y_{ivt})\big)}{\text{Var}\big(\Delta\text{Ln}(Y_{ivt})\big)} \qquad \text{(C3)}
\end{aligned}$$

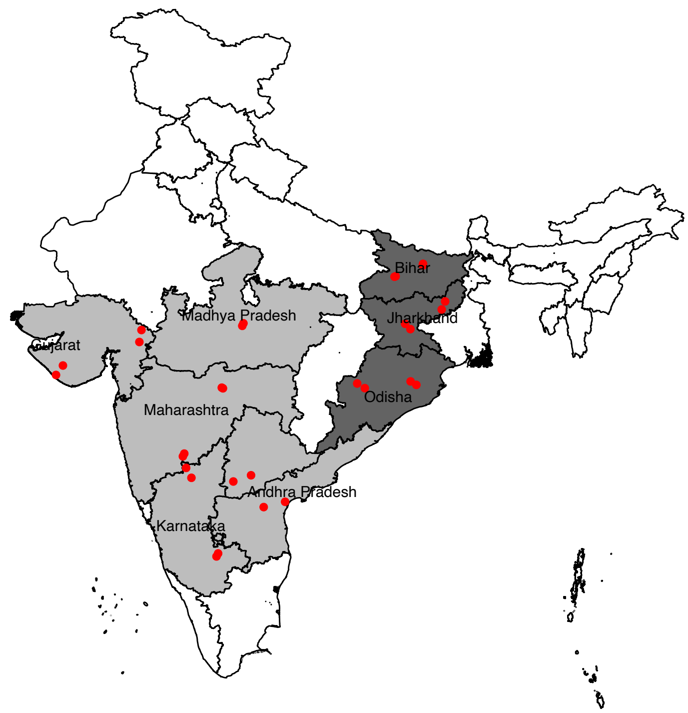
Or

$$1 = \frac{\text{Cov}(y_{ivt} - y_{ivt}^{P}, y_{ivt})}{y_{ivt}} + \frac{\text{Cov}\left(y_{ivt}^{P} - y_{ivt}^{S}, y_{ivt}\right)}{y_{ivt}} + \frac{\text{Cov}\left(y_{ivt}^{S} - c_{ivt}, y_{ivt}\right)}{y_{ivt}} + \frac{\text{Cov}(c_{ivt}, y_{ivt})}{y_{ivt}} \qquad \text{(C4)}$$

where the lowercase variables denote variables in log first differences. Note that these terms are regression coefficients and can be written concisely as:

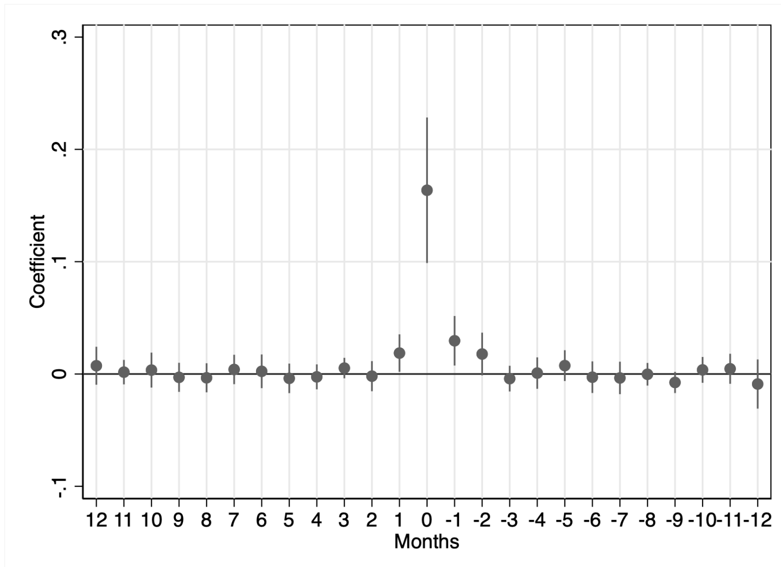
$$1 = \beta^{P} + \beta^{S} + \beta^{O} + \beta \qquad \text{(C5)}$$

Figure A1. Geographic location of sampled village



Note: Figure shows the geographic location of the 30 sampled villages across 8 states of India.

Figure A2. Lead and lagged milk production and risk sharing



Notes. The figure plots the estimated coefficients of 12-month lead and lagged log differenced milk production per person with 95% confidence intervals.

Table A1. Channels of risk-sharing with other controls

	(1)	(2)	(3)	(4)
Proportion of production shocks smoothed out by	Purchases	Sales	Transfers	Residual
$\Delta\ y_{ivt}$	0.377***	0.293***	0.131***	0.198***
	(0.022)	(0.044)	(0.038)	(0.027)
Δ Log cons. of other milk products per person	-0.009	-0.119	0.446**	-0.318*
	(0.105)	(0.139)	(0.216)	(0.179)
Δ Log cons. of ghee per person	-0.477**	0.113	0.119	0.246
	(0.205)	(0.110)	(0.176)	(0.187)
Δ Log cons. of yoghurt per person	0.112**	-0.250***	0.052	0.087*
	(0.052)	(0.054)	(0.052)	(0.047)
Δ Family members	0.058***	0.007	0.036***	-0.101***
	(0.007)	(0.006)	(0.005)	(0.008)
Δ Log MPCE	-0.051***	-0.029***	-0.124***	0.204***
	(0.011)	(0.009)	(0.031)	(0.033)
		45578		

Notes: Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A2. Instrumented channels of risk-sharing

	(1)	(2)	(3)	(4)	(5)
	$\Delta\ y_{ivt}$	β^P	β^S	β^O	β
	First stage	Instrumental variable regressions			
Δ Dairy animals	0.527***				
	(0.074)				
$\Delta\ y_{ivt}$		0.337***	0.397***	0.085***	0.175***
		(0.036)	(0.057)	(0.032)	(0.030)
N			44759		
Δ Dairy animals (lag 1)	0.468***				
	(0.070)				
$\Delta\ y_{ivt}$		0.340***	0.418***	0.071**	0.167***
		(0.038)	(0.055)	(0.035)	(0.032)
N			41975		
Δ Dairy animals (lag 2)	0.410***				
	(0.064)				
$\Delta\ y_{ivt}$		0.338***	0.432***	0.064*	0.162***
		(0.042)	(0.056)	(0.036)	(0.038)
N			40593		
Δ Dairy animals (lag 3)	0.356***				
	(0.055)				
$\Delta\ y_{ivt}$		0.337***	0.415***	0.080**	0.162***
		(0.045)	(0.057)	(0.040)	(0.044)
N			39435		
Δ Dairy animals (lag 4)	0.297***				
	(0.045)				
$\Delta\ y_{ivt}$		0.339***	0.407***	0.085*	0.161***
		(0.049)	(0.059)	(0.044)	(0.053)
N			38345		

Notes: All regressions include household size and value of consumption as control variables. $\Delta\ y_{ivt}$ denotes seasonally differenced log per person household production of milk. Column 1 presents the first stage regression results. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A3. Scale of production, new roads, seasonality, and channels of risk-sharing: with all possible interactions

	(1)	(2)	(3)	(4)
	β^P	β^S	β^O	β
$\Delta\, y_{ivt}$	0.476***	0.208***	0.090**	0.225***
	(0.034)	(0.056)	(0.038)	(0.038)
HS	0.012**	0.014***	-0.021***	-0.004
	(0.005)	(0.005)	(0.008)	(0.007)
$\Delta\, y_{ivt} \times HS$	-0.062***	0.053***	0.027	-0.017*
	(0.010)	(0.015)	(0.017)	(0.010)
$NROAD$	0.073***	-0.005	0.071***	-0.139***
	(0.020)	(0.022)	(0.022)	(0.031)
$\Delta\, y_{ivt} \times NROAD$	0.045	0.060	-0.055	-0.050
	(0.049)	(0.073)	(0.054)	(0.058)
$HS \times NROAD$	-0.036***	0.031*	0.010	-0.005
	(0.008)	(0.018)	(0.014)	(0.022)
$\Delta\, y_{ivt} \times HS \times NROAD$	-0.069***	0.033*	0.052*	-0.016
	(0.022)	(0.019)	(0.032)	(0.028)
$WINTER$	0.006	0.006	-0.000	-0.012**
	(0.005)	(0.004)	(0.005)	(0.006)
$\Delta\, y_{ivt} \times WINTER$	0.003	0.008	-0.020	0.009
	(0.010)	(0.016)	(0.015)	(0.014)
$HS \times WINTER$	-0.003	-0.003	0.005	0.001
	(0.003)	(0.004)	(0.004)	(0.004)
$\Delta\, y_{ivt} \times HS \times WINTER$	-0.014**	-0.009	0.027**	-0.004
	(0.007)	(0.011)	(0.012)	(0.007)
$NROAD \times WINTER$	-0.019	-0.016	-0.016	0.050
	(0.031)	(0.021)	(0.021)	(0.038)
$\Delta\, y_{ivt} \times NROAD \times WINTER$	-0.002	-0.010	0.028	-0.015
	(0.026)	(0.033)	(0.030)	(0.044)
$HS \times NROAD \times WINTER$	0.013	0.011	-0.017	-0.007
	(0.014)	(0.012)	(0.028)	(0.030)
$\Delta\, y_{ivt} \times HS \times NROAD \times WINTER$	-0.007	-0.007	-0.047*	0.061
	(0.012)	(0.015)	(0.026)	(0.039)
		45578		

Notes: All regressions include household size and value of consumption as control variables. $\Delta\, y_{ivt}$ denotes seasonally differenced log per person household production of milk. HS is the average herd size of a farm household during the entire period. NROAD captures new rural road construction under the PMGSY. WINTER is a dummy variable that takes values 1 for October, November, December, January, February, and March. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A4. Scale of production, new roads, seasonality and consumption smoothing via milk purchases

	(1)	(2)	(3)	(4)	(5)
$\Delta\, y_{ivt}$	0.479***	0.480***	0.479***	0.480***	0.483***
	(0.044)	(0.044)	(0.044)	(0.044)	(0.044)
$\Delta\, y_{ivt} \times HS$	-0.061***	-0.061***	-0.061***	-0.061***	-0.059***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
$\Delta\, y_{ivt} \times NROAD$	0.039	0.037	0.038	0.036	0.061
	(0.056)	(0.060)	(0.056)	(0.059)	(0.052)
$\Delta\, y_{ivt} \times WINTER$	0.002	0.002	0.003	0.003	0.003
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
$\Delta\, y_{ivt} \times HS \times NROAD$	-0.067**	-0.068**	-0.066**	-0.068**	-0.063**
	(0.020)	(0.022)	(0.021)	(0.023)	(0.025)
$\Delta\, y_{ivt} \times HS \times WINTER$	-0.014**	-0.013**	-0.014**	-0.013**	-0.012**
	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)
$\Delta\, y_{ivt} \times HS \times NROAD \times WINTER$	-0.009	-0.010	-0.009	-0.010	-0.012
	(0.011)	(0.011)	(0.012)	(0.011)	(0.011)
Village FE	Yes	No	Yes	No	Yes
Household FE	No	Yes	No	Yes	No
Month FE	No	No	Yes	Yes	Yes
Year FE	No	No	Yes	Yes	Yes
Village × Month FE	No	No	No	No	Yes
Village × Year FE	No	No	No	No	Yes
N	45578	45544	45578	45544	45541

Notes: All regressions include the change in household size and change in log of per member value of consumption as control variables. $\Delta\, y_{ivt}$ denotes seasonally differenced log per person household production of milk. HS is the average herd size of a farm household during the entire period. NROAD captures new rural road construction under the PMGSY. WINTER is a dummy variable that takes values 1 for October, November, December, January, February, and March. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A5. Scale of production, new roads, seasonality and consumption smoothing via informal transfers

	(1)	(2)	(3)	(4)	(5)
$\Delta\, y_{ivt}$	0.080*	0.078	0.080*	0.078	0.076*
	(0.043)	(0.045)	(0.043)	(0.045)	(0.041)
$\Delta\, y_{ivt} \times HS$	0.019	0.019	0.018	0.019	0.018
	(0.022)	(0.023)	(0.022)	(0.023)	(0.020)
$\Delta\, y_{ivt} \times NROAD$	-0.050	-0.038	-0.051	-0.039	-0.087*
	(0.051)	(0.050)	(0.050)	(0.050)	(0.044)
$\Delta\, y_{ivt} \times WINTER$	-0.015	-0.016	-0.015	-0.016	-0.017
	(0.014)	(0.014)	(0.014)	(0.014)	(0.017)
$\Delta\, y_{ivt} \times HS \times NROAD$	0.047*	0.043	0.048*	0.044	0.038
	(0.025)	(0.027)	(0.025)	(0.027)	(0.024)
$\Delta\, y_{ivt} \times HS \times WINTER$	0.026*	0.028*	0.026*	0.028*	0.025
	(0.014)	(0.014)	(0.014)	(0.014)	(0.016)
$\Delta\, y_{ivt} \times HS \times NROAD \times WINTER$	-0.023**	-0.024**	-0.022**	-0.023**	-0.022**
	(0.010)	(0.009)	(0.009)	(0.009)	(0.010)
Village FE	Yes	No	Yes	No	Yes
Household FE	No	Yes	No	Yes	No
Month FE	No	No	Yes	Yes	Yes
Year FE	No	No	Yes	Yes	Yes
Village × Month FE	No	No	No	No	Yes
Village × Year FE	No	No	No	No	Yes
N	44797	44763	44797	44763	44760

Notes: All regressions include the change in household size and change in log of per member value of consumption as control variables. $\Delta\, y_{ivt}$ denotes seasonally differenced log per person household production of milk. HS is the average herd size of a farm household during the entire period. NROAD captures new rural road construction under the PMGSY. WINTER is a dummy variable that takes values 1 for October, November, December, January, February, and March. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A6. Scale of production, new roads and consumption smoothing via sales to formal and informal channels

	(1)	(2)
	Consumption smoothing via sales to	
	Formal channels	Informal channels
$\Delta\, y_{ivt}$	0.168***	0.047
	(0.049)	(0.045)
$\Delta\, y_{ivt} \times HS$	0.020	0.027*
	(0.012)	(0.015)
$\Delta\, y_{ivt} \times NROAD$	0.125*	-0.036
	(0.069)	(0.046)
$\Delta\, y_{ivt} \times WINTER$	-0.005	0.016
	(0.011)	(0.010)
$\Delta\, y_{ivt} \times HS \times NROAD$	0.054**	-0.028*
	(0.022)	(0.016)
$\Delta\, y_{ivt} \times HS \times WINTER$	0.007	-0.015*
	(0.007)	(0.008)
$\Delta\, y_{ivt} \times HS \times NROAD \times WINTER$	0.012	0.009
	(0.009)	(0.007)
N	45154	44677
Sales (%)	78.35	21.65

Notes: Formal channels include sales to cooperatives and private processors. Informal channels include sales to local agents, shops, and fellow farmers. All regressions include household size and value of consumption as control variables. $\Delta\, y_{ivt}$ denotes seasonally differenced log per person household production of milk. HS is the average herd size of a farm household during the entire period. NROAD captures new rural road construction under the PMGSY. WINTER is a dummy variable that takes values 1 for October, November, December, January, February, and March. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A7. New roads and state-level dairy processing capacity

	(1)	(2)	(3)
	Log dairy plants (both cooperative and private)	Log material consumed by dairy plants in rupees lacs	Log inputs consumed by dairy plants in rupees lacs
$UROAD$	-0.003	-0.006	0.001
	(0.008)	(0.011)	(0.011)
$NROAD$	-0.009	0.006	0.012
	(0.013)	(0.022)	(0.022)
N	295	295	295

Notes: All regressions include state fixed and time dummies. $\Delta\ y_{ivt}$ UROAD, and NROAD capture either village road upgradation or new rural road construction under the PMGSY respectively. Figures in parenthesis are standard errors robust to the intra-state correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A8. Scale of production, dairy processing plants, seasonality and channels of risk-sharing

	(1)	(2)	(3)	(4)
	β^P	β^S	β^O	β
$\Delta\, y_{ivt}$	0.473***	-0.260***	0.424***	0.363***
	(0.092)	(0.099)	(0.142)	(0.106)
$\Delta\, y_{ivt} \times HS$	-0.076***	-0.041	0.204***	-0.087***
	(0.024)	(0.027)	(0.031)	(0.028)
$\Delta\, y_{ivt} \times PPLANT$	0.002	0.108***	-0.077***	-0.032
	(0.018)	(0.020)	(0.030)	(0.027)
$\Delta\, y_{ivt} \times WINTER$	0.003	-0.013	0.004	0.005
	(0.010)	(0.012)	(0.009)	(0.014)
$\Delta\, y_{ivt} \times HS \times PPLANT$	0.001	0.018***	-0.035***	0.015**
	(0.005)	(0.005)	(0.006)	(0.007)
$\Delta\, y_{ivt} \times HS \times WINTER$	-0.013	-0.017	0.043**	-0.012
	(0.015)	(0.012)	(0.021)	(0.015)
$\Delta\, y_{ivt} \times HS \times PPLANT \times WINTER$	-0.000	0.006**	-0.009**	0.004
	(0.003)	(0.003)	(0.004)	(0.003)
N	45578			

Notes: All regressions include household size and value of consumption as control variables. $\Delta\, y_{ivt}$ denotes seasonally differenced log per person household production of milk. HS is the average herd size of a farm household during the entire period. PPLANT is the log of dairy processing plants (both cooperative and private) at the state level. WINTER is a dummy variable that takes values 1 for October, November, December, January, February, and March. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A9. Change in stocks of other commodities and risk-sharing

	(1)	(2)	(3)
Dependent variable: seasonally differenced log milk consumption per person			
$\Delta\, y_{ivt}$	0.200***	0.200***	0.200***
	(0.027)	(0.027)	(0.027)
Δ Log cereal stocks quantity per member	0.006	0.009	
	(0.008)	(0.008)	
Δ Log pulses stocks quantity per member		-0.014	
		(0.009)	
Δ Log value of total stocks per member			0.006
			(0.008)
N	45578	45578	45578

Notes: All regressions include household size and value of consumption as control variables. $\Delta\, y_{ivt}$ denotes seasonally differenced log per person household production of milk. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A10. Savings, asset sales, other financial transactions and risk-sharing

	(1)	(2)	(3)	(4)	(5)
$\Delta\ y_{ivt}$	0.200***	0.200***	0.200***	0.200***	0.200***
	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)
Δ Log savings per member	-0.004				
	(0.004)				
Δ Log withdrawal per person	-0.003				
	(0.003)				
Δ Log durables purchased per member		-0.008**			
		(0.004)			
Δ Log durables sold per member		-0.002			
		(0.005)			
Δ Log loans taken per person			-0.004**		
			(0.002)		
Δ Log loans given per person			0.001		
			(0.002)		
Δ Log gifts received per person				-0.000	
				(0.002)	
Δ Log gifts given per person				0.004	
				(0.003)	
Δ Log land purchased per person					0.006
					(0.004)
Δ Log land sold per person					-0.015
					(0.009)
N	44779	44779	44779	44779	44779

Notes: All regressions include household size and value of consumption as control variables. $\Delta\ y_{ivt}$ denotes seasonally differenced log per person household production of milk. Figures in parenthesis are standard errors robust to the intra-village correlation of residuals. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.