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OLLI SALMENSUU

Essays on potato prices in developing countries

Exploring potato potential as a time-tested tool
for poverty alleviation and affordable welfare

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ABSTRACT

Could the potato attain such an important role in present-day developing countries as it generally had occupied by the 19th century in European history? As a cheap and healthy source of nutrition the potato would make a difference in the building of emerging economies, by affording food security for the poor while simultaneously helping the growers escape poverty, as was its historic role in temperate climate growing and storage conditions of the developed world. In this thesis we approach the task from five different viewing angles of potato price; i) across time, studying how historical evolving importance of the potato influences its status, consumption, production and prices in the progress of development, ii) price variation across country-borders, studying factors behind developing country cross-border price level differentials, iii) price variation in spatial dimension, particularly within-border market integration, iv) price fluctuation locally in temporal dimension, including financial speculation in supply and demand, and v) price models and theories.

Our major find in data dimension reduction underlines research potential in potato price systems for understanding structures of poverty. The four principal components which statistically significantly explain potato producer price naturally translate into basic factors of production – land, labour,

capital, and technology. This research also contributed by demonstrating, from general economic theory, how these classic factor inputs through their prices are central in determining long run average potato prices in developing countries. Explanatory shares agree with research on cross-country income differentials, expanding potato price research as a tool for approaching mechanisms of inclusive growth and welfare. General development paths of these macroeconomic inputs suggest considerable potential improvement from efficiency in technology use. The results may be applied particularly in recognising country-specific needs vis-a-vis input levels and prices by directing public policy so that sustainable input use is strengthened, while securing the price incentive received by the growers.

Aiming for a closer view into a developing country with many characteristic problems of underdevelopment that has striven to unleash its potato potential through cold storage adaptation and technology aided cultivation in subtropical lowlands in the proximity of potato consuming urban masses, India was selected for further studies on potato price transmission and fluctuations which affect wide differentials between producer and consumer prices. A wide middleman margin harms particularly the poor even where the potato has improved notably its social and nutritional importance. Grower incentives and wider potato use in developing countries generally weaken with increasing dealer share for carrying risks and other costs due to distance between production areas and urban centres in uncertain transport and storage conditions. Analysing Indian potato market integration, Engle-Granger-type error correction models evidenced slower price integration in the capital city area compared to other studied markets, indicating presence of food price speculation in Delhi as its centrality would normally lead the odds to opposite direction. Food price speculation in Delhi was demonstrated by a rolling window Granger-causality testing (RWGCT) based methodological framework for spotting unexpected demand or supply shifts. The logic and persistence in results, particularly concerning increased detection of demand side speculation during food price crises of 2007-2009 and 2011-2012, confirmed the framework. As a complementing price analysis, this research also contributed a tailored Bayesian regime-switching model for price forecasts in Delhi potato markets.

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TIIVISTELMÄ

Voisiko peruna saavuttaa nykyajan kehitysmaissa yhtä tärkeän roolin, kuin sillä oli Euroopan historiassa 1800-luvulta lähtien? Halpana ja terveellisenä ravinnonlähteenä peruna toisi nousevien talouksien syntyyn ruokaturvaa ja viljelijöille tien ulos köyhyydestä, mikä rooli sillä olikin lauhkean vyöhykkeen kasvu- ja säilyvyysoloissa kehittyneiden maiden historiassa. Tämä väitöstutkimus lähestyy aihetta viidestä eri perunan hintoihin liittyvästä näkökulmasta: i) yli ajanjaksojen, eli kuinka perunan merkityksen historiallinen kehitys talouden kasvaessa vaikuttaa sen statukseen, kulutukseen, tuotantoon ja hintoihin, ii) hintavaihtelu maiden rajojen yli, eli kehitysmaakohtaisia hintatasoja aiheuttavat tekijät, iii) alueiden välinen hintavaihtelu, erityisesti maanrajojen sisäinen markkinaintegraatio, iv) paikallinen hintavaihtelu ajassa, mukaan lukien kysyntä- ja tarjontapuolen keinottelu, ja v) hintamallinnusta ja -teoriaa.

Datan ulottuvuuksien vähentämisen päälöydökset korostavat perunahintasysteemin potentiaalia köyhyyden rakenteiden tutkimukselle. Neljä pääkomponenttia, jotka selittivät tilastollisesti merkitsevästi perunan tuottajahintaa, paljastivat luonnollisesti päätellen perustuotannontekijät: maa, työ, pääoma ja teknologia. Tämä tutkimus niinikään kontribuoi osoittamalla yleisestä talousteoriasta lähtien, kuinka kyseiset klassiset panossyötteet hintojensa

kautta selittävät kehitysmaakohtaisia pitkän aikavälin keskimääräisiä perunahintoja. Selitysosuudet ovat yhtenevät maiden välisiä tuloeroja koskevan tutkimuksen kanssa, mikä laajentaa perunahintatutkimusta välineeksi, jolla lähestyä osallistavan kasvun ja hyvinvoinnin mekanismeja. Näiden makrotaloudellisten panosten yleiset syntypolut viittaavat huomattavaan teknologisen tehokkuuden käyttämättömään potentiaaliin. Tuloksia voi hyödyntää erityisesti tunnistamalla maakohtaisia tarpeita liittyen panostasoihin ja hintoihin sekä edeten toimiviin politiikkaratkaisuihin, jotka vahvistavat kestävää panoskäyttöä samalla kuitenkin turvaten viljelijöiden hintakannustimet.

Tarkoituksena oli myös saada lähempi näkymä kehitysmaasta, joka on monista kehityksen tunnusomaisista ongelmista huolimatta pyrkinyt vapauttamaan perunan potentiaalia kylmäsäilytyksen ja teknologisen viljelyn kautta subtrooppisilla alangoilla, lähellä suurten kaupunkien kuluttajamassoja. Intia valittiin laajoja eroja tuottaja- ja kuluttajahintojen välille vaikuttavien perunahintavälitysten ja -vaihteluiden tutkimuskohteeksi. Suuret välittäjäkatteet ovat haitaksi erityisesti köyhille, vaikka peruna olisi jo huomattavasti lisännyt yhteiskunnallista ja ravitsemuksellista merkitystään. Viljelijäkannustimet ja perunan käyttö heikkenevät kehitysmaissa yleisesti tuotantoalueiden ja kaupunkikeskusten etäisyyksien ja epävarmojen kuljetus- ja säilytysolojen tuomien riskien, kulujen ja välittäjäosuuksien kasvaessa. Intian perunamarkkinaintegraation analysoinnissa Engle-Granger-virheenkorjausmallinnus toi esiin hitaampaa hintaintegraatiota pääkaupunkialueella verraten muihin tutkittuihin markkinoihin, mikä viittasi hintakeinotteluun Delhissä, jonka keskeinen asema normaalisti antaisi odottaa päinvastaista. Ruokahintakeinottelu Delhissä näytettiin toteen rullaaviin Granger-kausaalisuustesteihin perustavalla metodologisella kehyksellä, joka tunnistaa odottamattomia kysyntä- tai tarjontasiirtymiä. Saatujen tulosten loogisuus ja pysyvyys, erityisesti koskien tunnistettua lisääntynyttä kysyntäpuolen keinottelua ruokakriisien 2007-2009 ja 2011-2012 aikana, toimi vahvistuksena myös metodologiselle kehykselle. Täydentävänä hinta-analyysina kokonaisuutta tukee räätälöity Bayesiläinen tilanvaihtomalli Delhin perunamarkkinan hintojen ennustamiseen.

Avainsanat: Perunan hinta, Talouskasvu, Kehitysmaat, Tarjontarajoitteet, Tuotannontekijät, Maatalouskehitys, Kehitys ja terveys

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This thesis was seeded by a simple thought that entered my mind 13 years ago to “Study the poorest social structure, potato price”. Reading on the topic led me to marvel the potato, for its silent nutritional importance throughout my own life as well.

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I also thank my employers. Although working for other projects slowed down my work on this thesis, learning how societies function continued. A particularly enlightening moment occurred near midsummer 2014 while working in a FAO project, programming forest inventory statistics for Bac Giang province. At lunch-break near communist Hanoi, as we sat at the table with seafood and rice, my Vietnamese colleagues, who seemed notably thankful and even proud for having plenty of food in recent years, inquired about my eating habits in Finland. “Potatoes with fish” provoked no enthusiasm. The potato, cheap basic food in Finland, remains relatively expensive in Vietnam and many other developing countries where its consumption starts from affluent people. Such encounters intrigued my mind and motivated this thesis. What prevents the affordability of potatoes for general consumption and how to reach it for improved general welfare and food security in developing countries?

Kerava, May 19, 2021
Olli Salmensuu

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1 Introduction

1.1 Thesis motivation

The potato's 16th century arrival to European fields of temperate climate from its origin at South American Andean highlands brought a positive agricultural productivity shock of historic dimension that still continues. As basic elements of living started improving in the proximity of these cultivation areas where the potato triumphed, a handful of North European countries received a differentiating boost and stability to their urban and industrial expansion due to improved food security; these edges, induced from nutritional improvements, together with unprecedented support in population regeneration amidst reoccurring periods of warfare, destined in the following centuries major potato eating European nations to world dominion by competition in colonial exploitation. With their colonial rule, the potato spread across the globe, everywhere differentiating areas by its adoption and ensuing nutritional and social benefits. As it become an affordable staple, the potato facilitated economic growth and ameliorated social and nutritional equity in many countries. According to Nunn and Qian (2011), the potato became responsible for one-fourth of the increase in population and urbanisation in the Old World between 1700 and 1900 as it spread across the globe with Europeans. Furthermore, the same study found that the potato through improved nutrition induced a positive health effect as evidenced by increased adult heights. Increased welfare often turned the potato into an inferior good, so that, in our contemporary potato abundant developed world, it usually faces per capita consumption declines with rising incomes as people diversify their consumption habits; this trend dominates although on the one hand potato based, healthy diets remain cheap and on the other hand processed potato products such as salty crisps and French fries remain popular as a part of unhealthy diets and lifestyles which create obesity problems in the midst of the plenty (Ouhtit et al. 2014; Mesías and Morales 2015; Just and Gabrielyan 2016; Rana et al. 2017; Waterlander et al. 2018). Even though developing countries are slowly catching up, it is apparent that a similar potato fuelled rise from poverty has obstacles in developing countries of today unlike experienced in Europe, the historic base of potato dissemination. Potato prices are relatively high in many developing countries of tropics and subtropics as supplies to critical urban areas face constraints, due to low capital and technology penetration in production and challenging transport and storage of this bulky and perishable produce from cooler highland areas where climate and soil resemble European fields. Low production due to supply constraints naturally keeps the prices high and out of the reach of the poorest.

Scientific endeavours seek and expose suitable grounds of research inquiry; the common fruit fly possessed properties which were beneficial for constructing and testing theories in biological studies (Jennings 2011), whereas chess was a game with characteristics that suited particularly well developing computing and artificial intelligence (Ensmenger 2011). Similarly, as described in this thesis, economic and social properties attributable to the domain of potato prices in developing countries prompt to expect fruits from its separate study. Such fruits blossomed particularly in Essay **II** with the discovery of classic factors of production from a novel angle, via empirical dimension reduction, and their explanation of cross-border potato price levels with similarity in explanatory power to more established research on income level differentials. This similarity further increases the potential of the research that seeks to answer how potato price system affects structures of underdevelopment. In addition to persistent supply constraints, a particularly noticeable characteristic for developing country conditions is that national borders hinder market integration. The bulky and perishable potato even provides a classic example of tariff escalation due to widely existing import tariffs on potatoes and potato products (Prakash 2008; Cromme et al. 2010).

Considering local studies for particular market mechanisms within a developing country, India appears as a country where specialised research has potential to extract typical phenomena related to mass poverty in quantitatively distinguishable measure; dualism of the economy is deep, and also although India has made great strides in potato use, still concerning cross-border trade it is nearly autarkic, and suffers from wide middleman margins and farmer poverty. Whereas in many developing countries potato price fluctuation has apparently little social effect, the potato has, in some countries, overcome many obstacles to production incentives and become so widely used that seasonal high prices that hit the poor consumers even lead to riots. Essays **III-V** take a closer look on potato markets in India, with emphasis on price transmission and fluctuation which remain a major problem for many urban centres where potato is widely used, thus also paramount importance relates to potato prices in capital Delhi.

1.1.1 Prices first – right prices bring production and consumption

Why is studying prices so important – why not simply put effort to increase potato production in developing countries which would lower prices?

Firstly, we should understand that potato production levels remain low in many developing countries for differing reasons that relate to prices. High consumer prices curb demand whereas low producer prices restrain supply. Both usually coexist. Contrary to its potential in helping nutritional requirements of the poorest, for contemporary developing countries the potato is usually a relatively expensive vegetable due to constraints on supply (Scott 2002; Lal et al. 2011; Devaux et al. 2014). In countries with subtropical and tropical climate potato production is often located in remote highlands far from population centres. Risks in potato storage and transport accentuate their related costs and middlemen margins. Wide seasonal price cycles and weakly integrated markets call for speculative hoarding which adds up making potato unaffordable as year-round nutrition for the poor masses. In economics literature agricultural production is ordinarily attributed to factor inputs through a production function. Inputs are costly and stubborn but misguided attempts to increase production without efficient and sustainable input coordination may easily turn out to be in vain. Particularly when acting against the tendencies of the long run, such as entrepreneurial incentives of the countryside compared to urban areas, we can not ignore the price view to increasing potato production and importance.

Secondly, for research and social reasons, we will benefit from the viewing detail and observability that the price angle will bring. Particularly in understanding local and national reasons behind production, the price angle should help research since developing country cross-border trade is very limited and prices are more observable than production. For social reasons we would wish to decrease potato price for its consumers, but increase the economic incentive for the growers. Such changes in the price system would naturally and sustainably increase both production and consumption of potatoes. Then, increased agricultural productivity spurs sustained economic growth through releasing resources to other sectors and also raises the nutritional status of workers (Johnston and Mellor 1961; Evenson and Fuglie 2010).

1.1.2 Potato's minor role in present-day developing countries

There is a common misconception, stemming from the history of the potato as a food for the poor and its common inferior good status in developed countries, that the potato would be everywhere an inexpensive food item and its low use would be due to tastes of people inhabiting developing countries (Scott 2002; Reader 2009). Comparing the role of the potato in present-day developing countries to the history of developed countries, there is a stark contrast. Whereas the potato in the history of many present-day developed countries became widely a staple food crop which – due to its health and welfare effects and affordability for the poor – levelled the living conditions brought by class differences, for contemporary developing countries the potato is more often a near-luxury food item for better-off people thus enforcing differences brought by class to health and overall welfare. When incomes rise, and people escape poverty, they wish diversify their food consumption, which increases the demand for the potato which does not belong to the usual diet of the poor in developing countries, Still, we have seen progress, notably India has been able to bring the potato production into subtropical lowland areas, in proximity of cities, in massive scale (Scott 2002; Kumar et al. 2015). This easing of supply during recent decades of the agricultural transformation has brought potato to a more central role, lowering prices so the poorest can at least seasonally more easily afford potatoes. Still, although the urban poor in Delhi enjoy from low priced potatoes for a couple of months following the main harvest, year-round potato nutrition is out of their reach. Arguably some income level rise and food security has occurred in India but still widespread poverty remains in the country. For northern

India, where the capital city Delhi is located, the main year-round dishes are roti (wheat) and dal (pulse), not potato. The current research, particularly its papers **III-V**, also answers to calls e.g. in Fuglie et al. (1997) for 'more in-depth exploration of price behaviour in the Indian potato market'.

1.1.3 Potato as a tool to cope with developing country food security

Cumulating knowledge on potato price affecting factors may help unleash the welfare increasing potential of the potato for the poor people that inhabit developing countries. Recent times of uncertainty, global pandemic, economic closures, social restlessness, and also aspirations for migration in hopes of better living conditions, both international but also rural-urban within country, and political needs for increasing the efficiency and targeting of direct development aid naturally put great emphasis for solutions which improve the livelihoods of the poor in developing countries locally and sustainably.

In addition, now also climate change threatens cultivation areas of the developing world (Muthoni et al. 2017; Zhang et al. 2018; Zhai et al. 2018; Pradel et al. 2019). With the loss of cultivated and arable land in developing countries coupled with political instabilities in developed countries also in matters relating to development policy and funding, the shocks in food security of the developing world are likely to lead into a future with increasing pressures for mass migration to the developed world. In its potential to mitigate these pressures, the potato possesses optimal attributes comparing to any other major crop; its produce is faster yielding, more nutritious in food content, requires less land to cultivate, and thrives in harsher climates (De Jong 2016). A large scale cultivation shift from current major food crops to potatoes would slow down the climate change by reducing energy consumption in production and related greenhouse gas emissions (Zhen et al. 2018). From the nutritional side, locally produced potato could play a big role in empowering developing country residents; also in areas where climate change is transforming agriculture (Kolech et al. 2015; Andrivon 2017). The potato produces more dietary energy than any other major food crop per unit of water. It out yields all the major food crops on a kilogram of energy per hectare per day basis. The potato suits to providing nourishing food not only under certain ecological conditions, its crop productivity even benefits from higher carbon dioxide levels of climate change, and comparing to major cereal staples the potato fits ideally to land scarcity for sustaining a growing population (Horton 1987; Scott 2002; FAO 2008; Haverkort et al. 2013; Rana et al. 2017; Mohammadzadeh et al. 2018; Su and Wang 2019). Furthermore potato varieties are developed that thrive in saline conditions anticipating sea level rising following climate change, when salt water is expected to spoil many coastal areas of traditional crop cultivation (Jha et al. 2017; Dahal et al. 2019; Wang et al. 2019; Ramírez et al. 2019). Not counting crop failures where over-dependence on potato was built, potato also easily supported growing populations in the history of modern developed countries.

Local food production, although aiding successful urbanisation, adds stress to agro-environment. In developing countries, this stress is often high to begin with, due to nearby residential pollution and industrial toxins, and is further increased as industrial waste water or urban sewage water irrigates cultivating fields in many areas. From the irrigating water, substances which are potentially dangerous also to human health, such as heavy metals and pharmaceutical compounds, transfer to edible plants and farm animals. Higher concentrations of these substances in the water and then in the fields inevitably and increasingly contaminate cultivated plants, to varying degree by their characteristics. Some of the metals are known to become quickly highly dangerous and some are with moderate intake even beneficial to human constitution. Therefore, research and planning should continue to evaluate which crop may be safely cultivated near certain type industrial sites, such as those operating in particular metal mining, and regulations with their controls must be upheld for the benefit of local inhabitants. In general, greater caution must be exercised and further research is needed also on potato cultivation using contaminated waters or in polluted areas although the potato plant possesses a surprising positive characteristic which benefits the well-being of its subsistence growers on marginal lands and consumers. Many of the potentially dangerous heavy metals, which industrial and urban areas release through contaminated waters and other pollution, accrue – contrary to conventional wisdom – in higher concentrations to inedible potato leaves rather than to its edible tuber, which is underground and thus even directly touches the polluting agents. This characteristic also differentiates it from e.g. cauliflower whose edible curb accumulates more pollutants compared to leaves, and again underlines versatile abilities of the potato to accommodate into changing environments. Knowledge of such plant characteristics which preserve human health, inviting also to increasing potato share of total cultivation, should prove valuable particularly in developing countries where health related regulations are lacking or unenforced (Brar et al. 2000; Antonius and Snyder 2007; Tack 2014; Malchi et al. 2014; Rai et al. 2015; Khan et al. 2017; Garrido et al. 2017; Peng et al. 2018; Nawab et al. 2018; Rai et al. 2019; Kaur et al. 2020).

1.1.4 Welfare and health effects of potato prices and consumption

Greater potato importance would also likely increase food security in local crises of poor countries since it is bulky and perishable compared to existing staples and thus less exportable to more affluent areas that have plenty of buying power. Same characteristics which make potatoes rare items for import and food aid could support population by existing local crops in times of distress. Positive health effects are likely in normal times as well. The poor often spend their little income on unhealthy foods where the affordable potato nutrition is out of their reach. As an example, although the exclusion of alcohol and other conspicuous consumption such as tobacco from the research could bias the results, measured welfare effects of food price changes in Mexico – where the poor mostly consume for food maize tortillas but also ’other foods’ i.e. sweets, carbonated beverages, coffee, sugar and vegetable oils – lead to a conclusion that potatoes are luxury articles for the poor (Attanasio et al. 2013). Often subsidy policies entrench existing staples and consumer habits. In India, minimum support prices for grains and the public distribution system in use are recognised to be in an urgent need of reform, but the intended cash transfer system would face same problems (Pingali et al. 2017). Lower consumer prices and wide availability of the potato would clearly target needs of the poorest, whereas heavily lobbied subsidies to grain farmers and social transfers based on existing registry data are less likely to be as useful in the same sense. For recent needs, research aimed at structural solutions concerning potato prices promises possibilities for policy changes that aid in supplying affordable potatoes for the urban poor; increasing incentives for potato production through the price system presents also an economically feasible solution with much welfare potential, comparing to such social transfer and subsidy systems which increase bureaucracy and foster structures of underdevelopment.

The potato is rich in essential human nutrients. It contains proteins, starch and fibre, minerals, vitamins, antioxidants, and phytochemicals. Its protein content suits particularly well human diet, its predominant carbohydrate is starch which provides energy, and its fibre lowers cardiovascular risk and obesity. With skin, potato fibre content rivals whole grain breads and pastas. Of its vitamins and minerals, particularly vital for human health are its abundant reservoirs of vitamin C and mineral potassium. Potassium reduces the risk of blood pressure, cardiovascular diseases and osteoporosis, whereas vitamin C reduces hypertension, and prevents scurvy. Both vitamin C and potassium also reduce risk of strokes. Beneficial enzymes and phytochemicals prevent cell injury, protecting e.g. eye health (McGill et al. 2013; Akyol et al. 2016; Singh and Kaur 2016; Gupta and Gupta 2019; Mishra et al. 2020; Burgos et al. 2020).

Glycaemic index classifies different sources of carbohydrate and carbohydrate-rich foods and their preparation by their postprandial glycaemic responses. Main factors in these responses are protein and fat in foods, which reduce glycaemic load by delaying gastric emptying and also by enhancing incretin and insulin secretion (Hätönen et al. 2011). Contrary to centuries of observed health benefits and cumulated research on its nutritional value, some studies implicated that a high glycemic index in potato causes health risks, particularly high blood pressure, obesity and type 2 diabetes (Camire et al. 2009), but recent research has thereafter heavily questioned the narrow glycemic load hypothesis, observing that reported health concerns relate more likely to a certain western diet and lifestyle, which correlates with health risks and includes potatoes, such as potatoes processed for fast food or their usual complementary consumption such as red meat (Hu et al. 2017; Andersen et al. 2018; Robertson et al. 2018; Beals 2019). Other potato parts except tubers are wholly avoided in order to omit high load of toxic glycoalkoloids. Similarly raw potato tubers are generally considered inedible and rarely consumed. Considering with the newest information common ways of preparing tubers for nutrition, consumption of baked, boiled, roasted, fried, or mashed potatoes, as also practised for centuries before recent years of research, appear as healthy alternatives, whereas salty crisps or French fries pose health hazards with high intake (Reader 2009; Larsson and Wolk 2016). Particularly in developing country conditions, however, where hunger is a visitor, the potato overshadows alternatives as its satiating effect is superior to wheat based pasta or rice (Geliebter et al. 2013; Akilen et al. 2016; Zhang et al. 2018).

1.2 Thesis objectives and scope

The scope of the thesis concerns potato prices in developing countries, nowadays often called also emerging economies. We are interested in aspects of potato prices that could potentially help build societal welfare by empowering the poor inhabiting developing countries who are currently deprived of the benefits that accrue from affordable every day potato consumption. Our interest touches producer, wholesale and consumer levels where prices with their interregional differentials and intertemporal fluctuations relate to potato trade and levels of use. Cumulated knowledge improves potato price explanation in various trade environments, thus aiding knowledge based regional policy action to advance potato importance, production and use in developing countries.

The objectives of the research are the following. As our first objective, we argue for potato role in development from recent potato price, consumption and national income data emphasising the differing potato importance in economics history between the developed and developing world (Essay **I**). The second objective is to identify explainers in cross-border potato price level differentials (Essay **II**). The third objective is to study intra-country market integration to gain insights concerning developing countries where the potential of the potato is less constrained by direct production constraints but rather by marketing constraints that keep high the middlemen risks and share, thus affecting a notable wedge between producer and consumer prices that keeps the rural potato producers poor and urban final consumers without reasonably priced potatoes (Essay **III**). Fourthly, we will present a framework that suits the study of speculation and other unexpected drivers of price which bring problems for econometric modelling and forecasting (Essay **IV**). Fifthly, we will tailor a price forecasting model (Essay **V**). With such objectives we are aiming for insights on potato price system to help unleash still largely unfulfilled potato potential in supplying affordable health and welfare in present-day developing countries.

1.3 Thesis structure

The thesis overview is structured as follows, aligned into two chapters that differentiate our data, research and results concerning determinants of potato prices into the long run (Chapter 2) and short run (Chapter 3). The long run view is explored in Essays **I-II** using decade-averaged cross-sectional producer price data, but it partially also relates to Essay **III** through long run dynamics of market integration. The short run analysis focuses on Essays **III-V** which use Indian time series data in daily, weekly and monthly frequencies. Chapter 4 then draws conclusions, presenting main contributions and recommendations for policy and continued research.

The five essays of the thesis follow themes that study *potato status and development*, *cross-border*, *intra-country integration*, *local fluctuation* – speculation emphasised – and *modelling* aspects of prices for insights on their variation.

Essay **I** studies potato importance touching also economics history. It also discusses how potato importance has been evolving with long time periods and how in this evolution different statuses of the potato – from luxury to inferior good – are related to its price in passing of the time and general economic growth. It also views the importance of the price system for pro-poor growth, and argues for research possibilities that may link potato prices in developing countries into cross-country income differentials. Essay **II** discusses weak cross-border market integration of the potato in developing countries. Together with commonplace existence of constraints on the supply, it allowed a discovery of determinants of potato prices through a data dimension reduction technique. Essay **III** studies intra-country market integration, presenting a market integration case study for Indian potato prices. Chapter 2 also pays attention to price transmission from producer to consumer prices with regard to vulnerable groups of particular social interest, the urban poor and poor potato growers. Chapter 3 complements discussion on potato price fluctuations in Essay **IV** where we develop a method for investigating when price and quantity adjustments are caused by financial speculation, seen as unexpected, speculative shifts in supply or demand, whereas presenting another research orientation on the theme, Essay **V** develops a Bayesian regime switching model for Delhi retail prices.

2 Prices, production and importance: long run view

The founder of economics Adam Smith foresaw already in the 18th century the high potential of the potato for population growth, sustenance and health, but he also recognised the major obstacle still preventing it to be fulfilled. The potato suffers from severe rotting compared to then existing staples, which rises merchant risks in storing potato, which through the price system is a constraint to its wider cultivation. Especially the developing countries usually have no adequate infrastructures and reliable electricity grids to conserve potatoes in tropical or subtropical climate. This eventually leads to a large wedge between producer and consumer prices due to transport and storage costs, low availability of potatoes in urban consumer markets, weak market integration especially concerning cross-border trade, and strongly seasonally cyclical prices where potatoes are available.

> 'The circumstances of the poor through a great part of England cannot surely be so much distressed by any rise in the price of poultry, fish, wild-fowl, or venison, as they must be relieved by the fall in that of potatoes.' (Smith 1904, (1776) par. I.11.238)

> 'Should this root ever become in any part of Europe, like rice in some countries, the common and favourite vegetable food of the people, so as to occupy the same proportion of the lands in tillage which wheat and other sorts of grain for human food do at present, the same quantity of cultivated land would maintain a much greater number of people, and the labourers being generally fed with potatoes, a greater surplus would remain after replacing all the stock and maintaining all the labour employed in cultivation.' (Smith 1904, (1776) par. I.11.49)

> 'The chairmen, porters, and coalheavers in London, and those unfortunate women who live by prostitution, the strongest men and the most beautiful women perhaps in the British dominions, are said to be the

greater part of them from the lowest ranks of people in Ireland, who are generally fed with this root. No food can afford a more decisive proof of its nourishing quality, or of its being peculiarly suitable to the health of the human constitution.

> It is difficult to preserve potatoes through the year, and impossible to store them like corn, for two or three years together. The fear of not being able to sell them before they rot discourages their cultivation, and is, perhaps, the chief obstacle to their ever becoming in any country, like bread, the principal vegetable food of all the different ranks of the people.' (Smith 1904, (1776) par. I.11.51,52)

In many countries potato progress into a staple food was accompanied by general positive wealth, welfare and health effects in population, also aiding city development (Nunn and Qian 2011). Essays **I-II** expand discussion concerning the potato's long run contribution to human welfare which has differed between the developed and developing world.

2.1 Demand

Avoiding complications due to the Giffen property, potato demand curve is downward sloping, i.e. the law of demand holds normally. Furthermore, potatoes have greater own-price elasticity of quantity demanded at lower prices, following the seminal statistical determination of the potato demand curve (Working 1925, quoting from p. 512).

> 'Another characteristic worthy of attention is the nature of demands included. The quantities shown to be consumed per day at various prices include all uses of potatoes, comprising not only human consumption on farms as well as elsewhere, but also consumption of potatoes for feed of animals, for manufacture of starch, and the wastage that attends handling at various stages, all the way from the potatoes left in the field by the farmer when prices are low to the potatoes served at table and thrown away uneaten. Low prices result in increased

consumption in all these lines and probably most effective in lines other than human consumption.

It is notable that the elasticity of the demand increases as the price decreases, [...]. This is reverse of Marshall's general law of variation of the elasticity of demand which is that "The elasticity of demand is great for high prices, and great or at least considerable, for medium prices; but it declines as the price falls; and gradually fades away if the fall goes so far that the satiety is reached." '

However, Marshall (2013, (1890) Book III, Chapter iv, p. 87) explained that the above rule for elasticity, i.e. responsiveness, of demand to price depends on commodities and consumer welfare, and instead of assuming a continuous rule at all prices, discussed low and high price levels that begin and end at some point, with exceptions concerning aggregate consumption. Similarly to the case studied by Working (1925), also urban centres in underdeveloped economies can hardly reach satiety in costless potato; also in such areas of mass poverty, compared to a more developed country situation with all its refined value adding uses of potato industry, the elasticity of demand is likely relatively weaker at higher prices.

2.2 Supply

Usually an upward sloping supply curve is unhesitatingly assumed. Suspicions against it have been raised since colonial times, and fixity-of-wants hypothesis is a major contradictory example where the poor, having satisfied their basic nutritional needs, limit their efforts despite economic incentives to work for even greater welfare (Ozanne 1999; Mayer and Glave 1999). The fixity-of-wants hypothesis is contested usually by social planner's neglect of the risks that poor peasants face (Todaro and Smith 2003, pp. 441-444). Thus, particularly for the long run as with Giffen property earlier, solutions can be more conventional. At extremes, in the long run supply could be infinitely elastic, i.e. horizontal, and prices co-integrated with the average cost of production in perfect competition, whereas between the harvest seasons in the short run, even if a part of the harvested crop is sent to nearby foreign markets, the aggregate remaining supply may become vertical, i.e. completely (or nearly) inelastic to current price level.

Often demand for potatoes would exist but supply constraints hinder producer incentives and attainability of affordable prices. Essay **II** establishes how knowledge, better alternative business, potato cultivation suitability and agricultural poverty affect producer prices as likely paths of accumulation of the classic inputs of production in macroeconomic scale. Sustainable increases in input use and their efficiency lead to increased potato production.

2.2.1 Weak cross-border trade integration maintains price differentials

Although Morshed (2007), studying multiple commodities in the context of national border creation at independence of Bangladesh from Pakistan, found no conclusive general evidence of price variability increasing in commodities for city-pairs located across the border, results of the study indicated that the national border is a reason to the variability in cross-border prices of the potato. Except for a single regression setting, national border creation was associated with a positive and statistically significant change to potato price variability in across border city-pairs. Compared to national production, cross-border potato trade is often negligible. Such an autarky keeps potato prices in neighbouring countries even substantially unintegrated, as also Essay **II** evidenced, simply due to inefficiencies in border crossing, transport and storage, and high duties and costs of marketing which are prevalent in many developing countries (Barrett 1999; Prakash 2008; Cromme et al. 2010). The bulky and perishable potato is not the select commodity for cross-border trade in developing country conditions due to poor infrastructure and intemperate climate, and it is also a rarity in food aid. National borders can also bring unanticipated delays which further increase the risk of rotting and weight loss of the cargo. Cross-border potato trade in developing country conditions needs special economic incentives, such as the potatoes cultivated in Bhutan or Nepal receive, as they can be profitably transported directly from the harvest to neighbouring Indian markets during the season of highest prices (Scott 1983; Brown and Kennedy 2005).

Country borders also act in limiting institutional frameworks. As institutions affect also potato markets as a part of a wider social structure, such research on institutions on economic development and borders is of some interest here. Generally the institution effect on economic development has been emphasised in literature since Acemoglu et al. (2001, 2002). Using satellite detectable light density at night as a proxy for African development, Michalopoulos and Papaioannou (2014) revealed that when same culture exists on both sides of the border, institutions are unimportant to development near country borders. However, this proxy, i.e. the light use at night, has little direct connection to cross-border potato transport and may also be culture dependent without direct linkage to development, which could bias the economic interpretation. Still, the results are sensible since institutions lose power farther from more populated areas, and particularly considering the potato scene in developing countries, with its heavy border duties, unofficial trade across the border becomes more likely for less populated areas with cultural homogeneity. Also regional controls exist in many areas, official or unofficial. We noticed in Essay **III** that the central area, Delhi, was slower in its price integration compared to other studied areas in India. Marketing efficiency likely weakens due to often cumbersome regulations on regional trade, more controllable by the official government near the populous capital city area. Remarkably also, often a developing country government may exert only weak influence in areas which locate far into the countryside, favouring the urban business atmosphere over rural as evidenced by results in Essay **II**.

2.2.2 Discovery of classic factors of production in dimension reduction

Supply constraints hinder potato production and use in developing countries, and additionally country borders maintain potato price level differentials due to poor integration in cross-border trade of this bulky and perishable product. These obstacles of life are, however, researcher edges which allowed a discovery by data dimension reduction, precursor in its way of confirming general economic theory and supporting wider use of such factor analytic methodologies in the domain of economics.

Essay **II** presents a principal component regression that notably benefits from the potato's weak cross-border market integration in developing countries. Potato producer price is regressed on the seven most important principal components formed of developing countries' agricultural and social data. Care in selecting original variables is important since results of the dimension reduction depend on the data. As an illustration, Bai et al. (2015) chose variables related to macroeconomic performance and received GDP correlating factor as the most important one, whereas Zou and Guo (2015) chose variables related to agricultural structure and received agricultural labour force correlating factor as the second most important factor. In Essay **II**, these components relate to PC1 'Economic growth' and PC2 'Agricultural poverty'.

In addition to the discouragement predicting unlikely success in the interpretation (Thomas 1997, p. 244), the methodology has been rarely used in economics as it suffers from two drawbacks. Firstly, scale sensitivity of the original variables and remedying it through standardising the variables has substantial effects on results. Secondly, the choice of principal components is not based on any relationship of the regressors (original variables) to the dependent variable (Greene 1993, p. 273). Still, these two last mentioned drawbacks remain problematic and sources for bias mainly when the method is used for the case of attempting to avoid multicollinearity and thus determine coefficient estimates for the original variables. The idea that is popular and seen useful in other sciences, namely interpreting or identifying factors based on their loadings, also sidestepping the two drawbacks above, remains largely strange to many economists. We should expect that, properly and carefully implemented, this approach should bring discoveries precisely in the largely neglected economic domain.

As a main discovery, we encounter the classic factor inputs of the agricultural production function; land, labour, capital and technology affecting potato producer prices in developing countries. General development paths of these macroeconomic inputs suggest considerable potential improvement from efficiency in technology use; land input was generally tied to local potato suitability, labour input to agricultural poverty – i.e. inexpensive workforce – and capital input depended on how enticing are alternative business opportunities in cities compared to using capital for land development, and national technology input correlated with or took form of knowledge built up locally during centuries of cultivation. The term used on this fourth factor of production whose level commands the productivity of other factors has been changing. In the ’Wealth of Nations’ such productivity advances carried the name ’the progress of improvement’, with no particular factor payment associated to early proprietors of such knowledge e.g. for more productive division of labour (Smith 1904, (1776)). Still already classical period economists more and more began to notice that monopoly in knowledge of operations – be it due to secrecy, or naturally or legally occurring – entitled its proprietors to factor payments similar to the rent of the land. Such a resemblance to land rents made Senior (1965, (1836) p. 91)) even class such ’knowledge of natural agents’ together with the land factor. In his ’Principles of Economics’ Marshall (2013, (1890)) called the fourth factor ’organisation’ from which, in economics, springs the field of industrial organisation. By no co-incidence the field focuses on issues of market structure and policy which relate to e.g. monopolies, product differentiation, patenting and technology. The relatively modern term ’technology’ for the fourth factor of production, although still also including advances which relate to governance of other factors, fits particularly well into the modern world reality of increasingly important role of corporate research spending and patent royalties which also bring payments to proprietors of such private research knowledge behind early application of technological and scientific advances (Rana et al. 2017).

Particularly concerning the potato scene, the knowledge accrued in potato cultivation during their colonial rule by European powers worked against the harmful effects which such generally extractive history left to the societies and business environments in present-day developing countries. As expanded in Essay **II**, the basis for potato cultivation in many developing countries comes from their colonial period where Christian religions had an important role. Especially PC6 or ’Better business’ and PC3 or ’Knowledge’ distinguish the two hands of an average Christian of the colonial times by their works. The one hand extracted material and human resources while the other hand brought food security and shared skills in potato cultivation. Both have left heritages, which are still enduring, to many developing countries. Their effect on current potato production through inputs used is opposite to each other. This result conforms to earlier influential research concerning religion effect on economic development. According to Weber (1950) and its followers, reformed Christian religions in Europe, North America and Australia helped historical growth. Acemoglu et al. (2001) could control away such cultural effects with institutions. The synthesis is advanced by the evidence in Essay **II**; religions affected many things, amongst other the potato spread and culture that empowered the poor masses and helped in the forming of both social equity and entrepreneurial spirit for institutions which have retained much of their historical form to present day.

Particularly increasing importance of the potato is likely to associate with increasing real wages as has generally occurred in the history of the developed world; PC4 or ’Potato importance’ results of Essay **II** also indicate a similar development occurring in many present-day developing countries. Potato induced technological and agricultural productivity growth coupled with democratisation of societies allowed both population and wage levels to increase simultaneously in western countries already at the time of the classical economists, stopping the era of Malthusian (Malthus 1798) population dynamics which based on diminishing returns on agriculture on limited lands where also population growth surpasses the ability of technological growth to increase food supply. Clearly, the theory heavily erred comparing an exponential rate of growth in human population to a supposedly linear rate of growth in food supply. The basic foods have much faster reproduction rates compared to population, and as the poor received potatoes to grow, whose supply quickly multiplied even on their marginal lands, the limitation of the theory concerning the limitedness of land clearly lost its prime. As modern times have seen great leaps in the capabilities for vertical construction and the use of artificial light, it should be admitted that it is not the resource base but a lacking organisation for more equitable division of food supplies which brings malnutrition and famine to developing countries which checks population growth. Wise leaders recognise advantages in supporting a greater population. The Malthusian theory is still commonly found in studies of economic history (Voigtländer and Voth 2013, for an example of wage level oscillating around subsistence) that have similar modelling needs as economics of developing countries where the potato potential, that has in history often surpassed even obstacles of unskilled pro-rich policies, still awaits its fulfilment.

2.3 Wedge between producer and consumer prices

Whereas easing constraints to supply at harvest, i.e. production constraints, is approachable by noting and taking action on inefficiencies related to national and regional factor input utilisation (Essay **II**), post-harvest supply constraints also exist. Such marketing constraints for the existing supply for their part discourage potato production, and also may lead to a large wedge between producer and consumer prices. Major marketing constraints include high costs which accrue from transport, physical losses in weight and spoilage during storage and marketing, and price instability in both temporal and areal dimension. These risks typically lead to a high middleman margin, the differential wedge between producer and consumer prices, which reduces farmer profits and supply of potatoes to consumers, thus seriously deterring potato cultivation and use in developing countries (Moon 2013; Chau et al. 2016; Scott and Kleinwechter 2017; Mitchell 2017; Sibhatu and Qaim 2018; Balachandran and Dhal 2018; Sharma et al. 2017; Mitra et al. 2018; Flachsbarth et al. 2018; Sodhi and Patel 2019; Devaux et al. 2020).

Figure 2.1 diagrammatically presents the basic problem that arises from constrained supply with its usual companion, high middleman margin. Let demand curve *D* represent demand from urban consumers, whereas S_o represents optimum supply, i.e. supply after subtracting minimum possible costs and losses from transport, storage, etc., for farm produce which is intended to markets. For simplicity of the presentation, in Figure 2.1, we assume that S_o still includes many of the costs and constraints which – whether price transmission between producer and consumer markets is areal or temporal or both – relate to production as in practice often the poor farmers in developing countries lack of proper inputs including technical knowledge in their use, so they are unable to supply at optimum of no production constraints unless their trading partners provide such help. Optimally, the price would be settled at P_o where quantity Q_o would be traded with no extra wedge between producer and consumer prices. With supply constraints, common in potato scene of developing countries, S_c corresponds to reduced supply to urban consumers, bringing equilibrium price P_u and quantity Q_c. Farmers receive price P_f to cover their costs, customers pay P_u and segments P_u-Q_c-P_f together with the y-axis form the middlemen share of sale value, which includes all added costs due to supply constraints including dealer risk premium for holding merchandise. This wedge between consumer and producer prices, i.e. middlemen share, although benefiting these entrepreneurs, is usually a loss for the potato, except for the part which induces greater competition among middlemen with improved services in transport and storage in potato marketing. The triangle formed of D-S_o-Q_c represents societal dead-weight loss due to constrained supply. The problem solution would include actions which remove supply constraints, allowing greater share to producers as well as cheaper potatoes in greater quantity to urban consumers. Better infrastructure including roads, telecommunications, and cold storage facilities would allow less spoilage, lower intra-year price variability and reducing of the differential between consumer and producer prices. Targeting particularly the potato sector, also concerning marketing constraints, should prove more beneficial than generally capitalising agriculture, considering particularly equitable division and economic growth. Currently existing high dealer margins in many developing countries furthermore encourage potato cultivation for subsistence only, failing to achieve the potato potential in farmer cash income and social benefits of promoting the potato for its potential as a healthy, affordable, staple food which smoothly reaches urban centres.

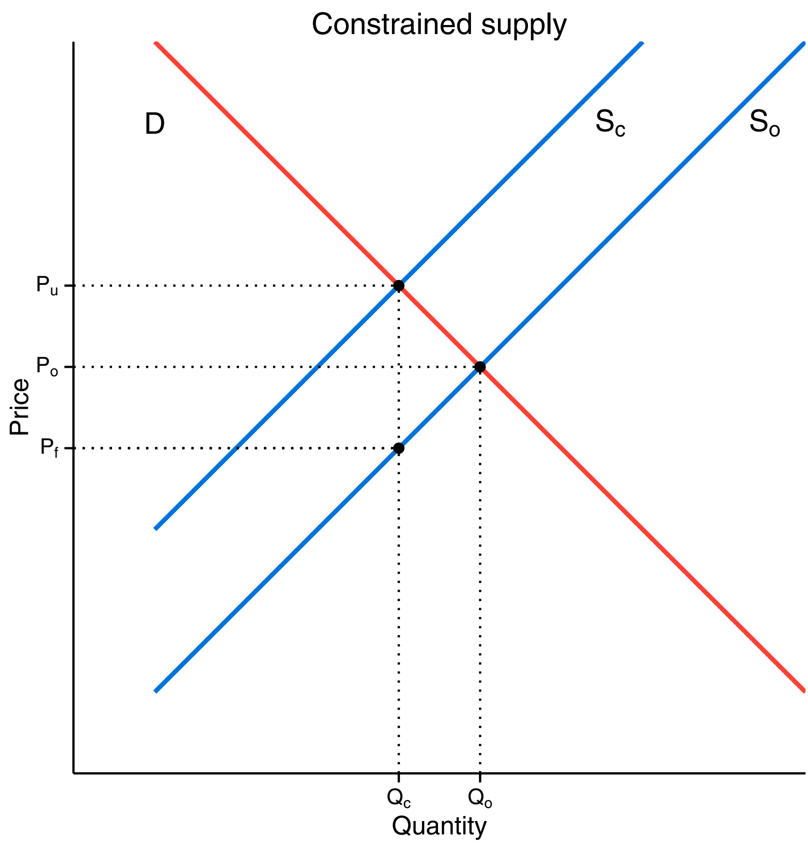

Figure 2.1: Constrained supply at S_c compared to optimum supply at S_o, with a wedge between urban consumer (P_u) and farm producer (P_f) prices for constrained supply quantity Q_c. This presentation intentionally has no scales. With extreme supply constraints, the supply may be completely price inelastic.

2.3.1 Marketing chains and price transmission

A review on food supply chain literature in developing countries (Routroy and Behera 2017) found that price transmission is the least-focused of the ten classified subtopics. Despite its relative neglect, it should be obvious that sustainable integration of poor farmers to high value markets holds promise of advancing the potato role and food security in developing countries (Tobin et al. 2016). Commonly in agricultural markets price transmission is asymmetric. An increase in producer prices is usually transmitted faster and more fully to consumer prices, whereas a decrease in producer prices is transmitted incompletely and at slower speed to consumer prices (Rajcaniova and Pokrivcak 2013). Jeder et al. (2017) studied price transmission in Tunisia. For potatoes the producer price guided transmission, whereas in tomato and green pepper markets, retail price changes were more easily transmitted to producer prices. The predominant marketing chain for vegetable crops (tomatoes, green peppers and potatoes) was the conventional circuit: producer – wholesalers – retailers – consumer. Studying particularly the potato marketing, other kinds of chains also exist; 1) farmers who sold potato to rural middlemen traders who sold to final consumers. 2) farmers who sold directly to urban traders or retailers who sold to final consumers. 3) farmers who sold to semi-wholesalers, or wholesalers, or urban traders through brokers (Kyomugisha et al. 2017; Sodhi and Patel 2019). It appears that particularly for the potato in developing countries, cultivation incentives are relatively independent of retail pricing, bringing often a major bottleneck that prevents the fulfilment of the potato potential in positively transforming the areas which suffer from poverty.

2.3.2 Market integration studies and speculation

Two main types of methodology exist for studying price integration between markets, Johansen (Johansen and Juselius 1990) and Engle-Granger (Engle and Granger 1987). Essay **III** employs an Engle-Granger type error-correction model to study potato market integration in India. Its results indicate that speculation in Delhi slows areal integration of prices near the capital city, comparing to other market areas. The existence of speculation in weakly integrated markets is no novelty. Historical famines present a notable research environment where weaker market integration may imply speculative behaviour of hoarders and merchants (Ó Gráda 1997, 2001, 2005; Ó Gráda and Chevet 2002). Ó Gráda (2005), studying pre-industrial famines in Europe, counters the idea in Smith (1904, (1776) par. IV.5.64) which suggested selling equal amount each time period as a merchant strategy. In practice all hoarding is likely rewarding in subtropical or tropical climate potato markets, as prices trend upwards each post-harvest period, for those who possess technology to avoid severe rotting. Due to uncertainties in transport conditions, border delays, and prices of abroad markets, merchants may opt to speculate on price rise in home markets even against common expectations; supply shifts with sellers' expectations or speculation on the near future price. A potato seller thus chooses the quantity to be sold in every period depending not only on current prices but also on storage possibilities and expected prices during each post-harvest storage period of potatoes. The supply of storage model in Subsection 3.2.1 expands this argument. In general, where the possibilities in transport, storage and cross-border trade improve, the volatility in potato prices lowers (Barrett 1997). The following Chapter 3 will return to study inter-temporal price fluctuation and speculation, with Essays **IV** and **V** keeping their focus on Delhi by developing a framework for locating speculative periods in competitive markets and a Bayesian model for price forecasting.

3 Price fluctuations

This Chapter on local intertemporal price fluctuations concerns its causing factors, particularly concentrating on changes in supply and demand in Delhi wholesale markets for potatoes and food price speculation which Essay **IV** examines in more detail. Aside potatoes, which suffer from weaker storage possibilities and seasonal fluctuation, speculation is a notable phenomenon also in the main cereal crops (Timmer 2009; Lagi et al. 2015). Lack of information often prevails and farmers speculate in potato prices, leading in many developing countries, including the origin of the crop Peru, to a typical seasonal pattern of overshooting price fluctuations from one year to next (Antazena et al. 2005, p. 71). Empirical research that assesses the effects from price behaviour is demanding. Welfare impacts of commodity price volatility, with data from Ethiopia, were studied in Bellemare et al. (2013). The finding was that food net sellers that are wealthier on average would benefit from stabler food prices, while for food net buyers who are poorer on average the variability is not as necessarily welfare reducing. This startling finding was contested by a replication study where more realistic household income imputations, based on observed minimum as opposed to using mean, returned common sense to the results; the poor suffer whereas the rich may benefit from food price volatility (McBride 2016). Still, we agree that the poor may be more easily introduced to the food commodity and thus slightly benefit from price swings if more wholesome nutrition such as potato becomes very affordable seasonally also to retail level. Still, from the viewpoint of farmer incentives that lead in the long run to potato advancement and its sustainable benefits, the variability clearly hurts also the urban poor in developing countries. This viewpoint and also discussion on empirical problems and model assumptions more generally is further expanded in Essay **IV**. We would wish that affordable potato nutrition would be available to all throughout the year, which has been supporting economies, even for centuries, in several temperate countries which have become the developed world. With marketing constraints faced by growers, the price variability hurts incentives for increasing production efficiency with added capital and technology inputs which could bring lower consumer prices, thus meeting the demand of urban masses (Zangeneh et al. 2015).

3.1 Demand and supply shifts

Price fluctuation, both year-on-year and within a market period, is in economics ordinarily approached by considering a shift in either supply or demand curve and a corresponding, usually lagged adjustment along the other curve to achieve a new market equilibrium. Short run changes in price occur because of demand or supply curve position shifts. Demand curve shifts may occur due to changes in population or substitute food prices, i.e. wheat or other vegetable prices. Shifts in supply may be caused by unexpected events like damaging weather during the critical tuber formation period. Both curves are also affected by changing expectations of higher or lower future prices.

3.1.1 Price-quantity adjustment to demand and supply shifts

Conventional perfect competition theory in connection with lagged price-quantity adjustments in Delhi potato wholesale markets sets up the stage for conventional rolling window Granger-causality testing (RWGCT) in Essay **IV**. In practice perfect competition is not known to exist in any market but there are many markets that can be thought as decent approximations for the theory. In economics, as usually assumed in market models, perfect competition leads to a market situation where no trader can by his own behaviour influence prices. Both sides of the trade, buyers and sellers, are price takers. See Debreu (1959) for a rigorous axiomatic presentation of perfect competition for economics. In the equilibrium supply and demand meet forming the market price. The seller can not sell any units of his supply above the equilibrium price and the buyer can not buy below the equilibrium price. A market of perfect competition is generally attributed with the following typical characteristics: many well-informed buyers and sellers with few barriers to entry or exit, buyers can easily switch between different sellers, sufficiently homogeneous products such as fresh potatoes, and with some lag buying and selling can accommodate to changed market conditions. Inference particularly on lagged effects due to unexpected, speculative supply or demand changes bases on logical steps 1-5 of the marketplace: 1) Both buyers and sellers are price takers according to the perfect competition assumption. 2) An existing equilibrium is disturbed by unforeseen speculative supply or demand change. 3) There is some lag in applying changes to wholesale market activities. 4) Due to the lag, buyers or sellers are not instantly changing their purchasing or selling schedules to the needs of eventually ensuing changed equilibrium quantities and prices. 5) Thus gradual price-quantity adjustment following the changed, supply- or demand-led, schedules towards the new equilibrium follows.

3.1.2 Indian potato market affecting factors

In India, for most of the year, the potato is relatively expensive at consumer point. The subtropical climate causes perishing of the crop; weak electricity availability, with block wide blackouts occurring even in cities, makes conservation of potatoes demanding. However, at year-change with the arrival of the main harvest season the potato becomes a cheap vegetable. This 'potato festival' – although few incentives accrue to the poor farmers from supplying potatoes for it – is helping even the poorest Indians to become accustomed to the potato, particularly for its hunger-defeating value, and acknowledgeable of its nutritional and health benefits (Scott and Suarez 2011; Andre et al. 2014).

Indian Commodity Exchange Potato Special Report (Anonymous 2009), among many sources, listed Indian potato market influencing factors. Naturally, these factors affect shifts to demand and supply curve positions. The factors affecting particularly in the demand side are comparative prices with respect to other vegetables in the domestic market, and potato demand from major cities and food processing industries. The factors affecting prices particularly in the supply side are planting and harvesting periods, variations in potato domestic acreage which base on yield and price realisation, crop development basing on weather progress in key growing regions i.e. cold waves and heavy rains which affect tuber formation, and transportation charges. Furthermore, as also Essay **IV** demonstrated, expecting above short-run shifts to supply and demand, potato growers and traders speculatively hoard the commodity in cold storage without spoilage up to 5-6 months before selling, in expectation of better prices.

3.1.3 Wholesale prices in Delhi: a market of perfect competition

The equilibrium theory for supply and demand in perfect competition is a natural choice as an assumption for the potato wholesale market of the Indian capital city Delhi. In most commodities, futures markets systematically influence trade in spot markets, or the other way round. Supporting our analytical focus on a single marketplace, potatoes provided no such evidence from Granger-causality tests on vegetables in Indian setting (Prasanna 2014; Ahmad and Sehgal 2015).

Potato price in Delhi follows a strongly seasonal cycle typical to poor countries of subtropical and tropical climate. Due to practically immeasurable number of the poor, even hunger threatened people, living in the city and its surrounding area, an artificial attempt to transform the underlying potato demand would be likely short in duration and unprofitably expensive endeavour. With numerous independent potato suppliers in surrounding areas of Delhi, the underlying supply can hardly be constrained by any cartel of sellers. This kind of underlying demand from retail customers or supply by potato growers is often blind to many essential business aspects of the potato trade, however, and also capital constrained to take advantage of business knowledge when it is available. This lack in resources often leads to cobweb type oscillation in annual producer prices (Nerlove 1958). In comparison, wholesale market participants are in the business of knowing all aspects of the potato trade, including retail demand and grower supplies, and they also have capital to profit wherever opportunities arise. With such informed and financially competent participants, daily formation of wholesale potato prices suits assuming perfect competition.

3.2 Speculation

Food price speculation affects lives of hundreds of millions of people. It is also reasonable to study it particularly in connection with the potato, whose price fluctuation is a constraint to its increasing production and growing use in developing countries. Detecting whether a supply or demand shift is behind price action could thus also help in removing constraints on production and use that spring from price instability. For the potato in many developing countries, such constraints are particularly documented on the supply side (Scott 2002; Lal et al. 2011; Devaux et al. 2014). The poor Anding county was turned into the 'potato capital of China' by a successful easing of the potato constraints on the supply side, but thereafter focusing on the demand side also (Zhang and Hu 2014).

The trend, or recent movements in price, or past seasonal variations in price level are usual reasons for the market participants to expect that higher or lower prices follow later in season. Although there is a well-known consensus of supply and demand roles in the price formation in market equilibrium, despite all discussion and hypothetical constructions, economists do not have a detailed theory how prices are determined - meaning a time path how the adjustment during the disequilibrium period is occurring towards the new equilibrium. Economists are often reluctant to regard their relations as causal, instead usually delegating them into the sphere of comparative statics. But in comparative statics, a temporal story of a shift precedes each new equilibrium (Hausman 1992, p. 49-50). Using Alfred Marshall's classic partial equilibrium representation, we describe in Essay **IV** how rational price-quantity adjustments work towards a new equilibrium in lagged response to cases of unexpected, speculative supply and demand curve movements, everything else held constant in the short-run.

3.2.1 Storage role in speculation

The gradual adjustment is connected to storage possibilities. Compared to retail customers and potato growers, wholesale market dealers more often have risk capital and possibilities to cold store potatoes for months, which may be very profitable when potato price is trending up. The potato is a commodity perishing more rapidly than the usual food imports and is never stored for more than a year unlike wheat or rice. Still it can be stored for months with appropriate technology even in subtropics of India. A justification for a framework on speculative short-term unexpected shifts for both supply and demand bases on the existence of inventories.

Deaton and Laroque (1992, 1995, 1996) set the direction for studying storage role in commodity price formation with emphasis on harvest periods and storage across years, with speculator inventory holders carrying stock from harvest season to next and even beyond whenever profits are expected. For evaluating how inventory in our case generally affects price expectations and equilibrium dynamics, consider the supply of storage model in Timmer (2009): $C_t = f_c(P_t, P^L)$; $H_t = f_h(P_t, P^L)$; $P_t^* - P_t = f_p(I_t)$; $I_t = I_{t-1} + H_t - C_t$, where C_t = consumption, P_t = current price, P^L = lagged price, H_t = production (harvest), I = inventory, and P_t^* = current expectation of the price in near future. Consumption, production at harvest, and difference between market expected price and current price are given by functions f_c, f_h and f_p. Concerning dependence of current and previous period (I_t, I_{t-1}) stocks held in inventory apart from supply and demand effects, firstly, price differences between time periods in a market of perfect competition where future prices can be forecast with certainty should reflect the cost of storage (Working 1949); considering the potato, lowering levels of supply due spoilage or adding costs of prolonged storing entail emptying inventories in post-harvest period. Secondly, as inventories and future prices are not known with certainty, storing of the commodity is a risky business (Fuglie 1999). Such uncertainty fuels speculation.

3.2.2 Detecting speculation in Delhi potato wholesale markets

Providing tools for detecting causal periods and corresponding directions of influence from empirical data is a step towards modelling that can also accommodate to the realism of market imperfections in developing countries. As we already expanded in the earlier Chapter 2, for the potato such realism includes supply constraints but also country borders and cumbersome regional regulations which, unlike many other commodities, hinder price integration and maintain cross-border price differentials, also in the Indian subcontinent (Morshed 2007). Looking the positive side, these same obstacles for trade are greatly favouring research which studies potato cross-border price differentials (Essay **II**), while it can also aid research that studies intra-country market integration (Essay **III**), or focuses on a single marketplace (Essays **IV-V**).

Essay **IV** presents a framework of speculative trading of supply or demand shifts that precede lagged, rational price-quantity reactions which bring new equilibria. Using RWGCT, it detects speculative supply and demand shifts from lagged responses which are due to changes in arrival quantity or price, thereby visually exploring at which time intervals statistical causalities between arrival quantity and price can be detected. High frequency data from Delhi potato wholesale markets allowed testing lagged market responses to unexpected supply or demand changes, which are much less likely to be correctly detected using monthly or quarterly data frequency although certain traces of specific types of speculation may be detected using such lower frequency data as well (Etienne et al. 2018). Rolling tests for fixed data window size were accomplished by looping, until all real price and arrival quantity data was exhausted, granger.test code of MSBVAR (Brandt 2012) package of R (R Development Core Team 2009) computing environment. Testing multiple same size time windows by RWGCT – instead of the more usual Granger-causality implementation of testing the whole data series in one piece – allows us to detect particular periods when causality exists as we test how prices affect quantities and vice versa using the idea of Granger causality.

3.3 On potato price models

This thesis developed price analysis particularly for Delhi potato markets. For forecasting short-run trends in Delhi retail prices, Essay **V** introduced a regime switching Bayesian model, where data updates posterior distributions of price trends, regime-switches, and cob-web oscillations. See Xiong et al. (2018) for a review on recent developments in agricultural commodity price forecasting. By conventions in vegetable – and more generally agricultural – price forecasting, Essay **V** focused on one-step-ahead forecasts. Tailored modelling in Essay **V** strives for realism complementing Delhi price behaviour analysis in Essay **IV** where RWGCT established periods of demand- or supply-side speculation in wholesale potato trade. For wholesale data, the theory of perfect competition could be assumed bringing solid structure for the research, whereas retail prices hold an appeal particularly for forecasting since they define potato use and status among the urban masses. Retailers also generally possess better knowledge than their customers, and often possess some local advantage against competition, and stand to gain by ignoring downward fluctuations that occur in wholesale markets specifically during post-harvest periods as prices climb. Still the forces that move wholesale prices are interconnected to retail pricing and modelling retail data does benefit from the knowledge extracted from wholesale data which are usually more amply available in higher frequency.

Similarly to the goal in Essays **IV-V** of seeking insights to improving on modelling realism, a ’chaotic’ model (Bacsi 1997, p. 450) was capable of producing fluctuations and sudden ’irregular’ behaviour as often experienced in price time series, which the majority of equilibrium models used in economics fail to describe. Also, Anjoy and Paul (2017) applied wavelet analysis on three Indian potato markets evading shortcomings of conventional ARCH/GARCH, as well as rigid assumptions of ARIMA which were used to forecast Delhi prices in Chandran and Pandey (2007); see also the discussion on the latter one in Essay **V** on Delhi forecasts.

4 Outline of thesis essays with conclusions

This thesis consists of five articles (**I-V**) on potato prices in developing countries together with their introducing and summarising part. All articles used empirical data, and this concluding Chapter shortly summarises main motivations for thesis essays, pinpointing main contributions in them, with possible implications and needs for added research.

4.1 History based idea for greater potato importance

This paragraph summarises the basic idea behind studying potato prices in developing countries. As expanded already in the beginning of the thesis, it would be socially desirable if the potato could possess the same role in present-day developing countries which it had from the 19th century onwards in European history. Optimally, as a cheap and healthy source of nutrition, the potato could bring food security for the poor consumers, and simultaneously, as a profitable endeavour, it could help the growers to escape poverty. Such was generally the historical role of the potato in many temperate climate countries, which we today call the developed world, as their societies evolved towards economic prosperity. Contrary to its potential, potato supply remains constrained in many present-day developing countries. Low producer prices and intra-season price variability offer insufficient incentives to the use of capital inputs and increasing efficient production, which would be ideally transmitted to lower consumer prices, meeting the demand of the poor, urban masses. Rather, high marketing costs together with high consumer prices often prevail – even though producer prices may be low – enforcing a stalemate position where better policy and potato orientated infrastructure improvements would be needed to solve it. Prompted by historical promises attached to a greater potato role and recognised present needs for improvement, which touch the price viewing angles, this thesis focused on the study of the potato price system to increase knowledge on reasons for the price variation, to promote conditions for wider potato use, and thereby also to support general social well-being in developing countries.

4.2 Empirical approach

The empirical approach in Essays **I-V** aimed to shed light on the above problems which limit the role of the potato in present-day developing countries by analysing potato prices and markets from different viewing angles.

4.2.1 Essay I: Potato price system and its importance for development

Essay **I** studies how potato importance has been evolving with long time periods and how in this evolution different statuses of the potato – from luxury to inferior good – are related to its price in passing of the time and general economic growth.

Local regressions on FAO data reveal that we receive likely more predictable and statistically significant, unbiased results on the potato price system on low income countries compared to rich countries.

4.2.2 Essay II: Principal component regression on cross-country data

In Essay **II**, principal components formed of social variables of 40 developing countries explained their decade-averaged potato producer price levels. Data dimension reduction which seeks to uncover hidden variables in the spirit of deep determinants research of development economics (Acemoglu et al. 2002, etc.) here revealed general determinants for the potato price level in developing country conditions. Its results provided explanations to why potato prices are high or low in developing countries. Taking into account country specific situations, the results also provided guidance to correct policy decisions for sustainable advances in potato sector even against tendencies, such as insecurity of the country-side, which operate in the long-run, and which may easily bring less guided attempts to increase national potato importance to naught.

4.2.3 Essays III-V: Time-series analyses on Indian data

Remaining articles, Essays **III-V**, proceeded to study potato prices in India and Delhi, where constraints on the supply have been eased, and low potato prices are achieved for the benefit of the poor consumers at least during the harvest season. Although India has succeeded in spreading potato production from high-elevation areas to subtropical plains, many other developing countries have failed in the task as farmers lack incentives to help underwrite costs of research to improve productivity and instead of subsidising potato cultivation some countries even have had policies of import subsidies for potato substitutes (Scott 2002; Devaux et al. 2020). Despite its advances related to technological inputs in subtropical lowland cultivation in past decades, also India still seems to be trapped in widespread poverty for the foreseeable future. To alleviate the situation further, we would wish that the potato growers would receive better rewards for their endeavours and that the urban poor would enjoy from lower consumer prices throughout the year. This wedge between consumer and producer prices prevents the poor from receiving the full benefits from so far achieved success in the removal of potato supply constraints. The studies for India thus aimed at finding solutions to the high middleman margin from price behaviour. Thus in a two-step procedure, in the first step focusing on cross-border price differentials, and then in the second step on middleman margins which relate to price fluctuation, integration, and transmission, in temporal and spatial dimension, this thesis studied from little explored price viewing angles the known problem of limited potato role in developing countries; we were thus seeking solutions that hold the potential to increase potato importance particularly in the poorest areas, which improvement holds the promise of replicating notable wealth, welfare and health effects which the potato provided in the history of present-day developed countries.

Essay **III** studied market integration within and between three Indian market areas. Analysing Engle-Granger type co-integration and error-correction models, our post-hoc reasoning encountered evidence that Delhi markets may attract food price speculation which diverts potato prices from their natural equilibrium level relationship with other markets. For growers on average, and especially for the poorer growers who are unable to store for months and time their sales of potatoes, eliminating price fluctuation altogether would be optimal. Wide availability of public infrastructure and storage technology could eliminate much of the fluctuation that is of seasonal nature, but the results also hinted that some markets could be particularly prone to speculative price movements, temporarily weakening their integration to other markets. Delhi wholesale and retail markets were further studied in Essays **IV** and **V** to gain insights on speculative price movements and to tailor a realistic price forecasting model, respectively. Essay **IV** studied short-run dependencies by RWGCT between arrival quantities and prices in Delhi wholesale markets for potatoes. Connected to the assumed perfect competition in the wholesale markets, the study detected speculation as initiated by either supply or demand shifts which disturb an existing equilibrium. The testing framework builds on departures from perfect competition as unexpectedly occurring, speculative shifts in demand and supply schedules are followed by lagged, rational adjustments by the other side of the trade before a new price-quantity equilibrium is reached. Essay **V** built a Bayesian regime switching model for potato price forecasting to study retail price behaviour in Delhi, which especially centred on the very expected drop in price caused by the main harvest but also accounted for less expected variations in price trend in the short run.

4.3 Main contributions

The main contributions of the thesis include the following, see also Table 4.1.

Due to the properties peculiar to cross-border potato trade in developing countries, i.e. that such bulky and perishable products maintain their price level differential across the national border, the potato price system provided an ideal approaching angle for searching explanations also concerning national production, the latter being harder to observe with similar accuracy in developing country conditions. Explaining potato producer prices in principal component regression, Essay **II** contributed a potentially precursory discovery; data dimension reduction revealed the classical basic factors of an agricultural production function; land, labour, capital, and technology.

The above result of identifying from real world data the classic factor inputs by dimension reduction validates core economic theory, as these basic factors – as abstract as they are – have existed since times of the early thinkers in classical political economy, i.e. more than two centuries, in theories of production; the component loadings also allowed linking these macroeconomic factor inputs to paths of their general accumulation in developing country conditions. Namely, the national land input for potato production is generally tied to local potato suitability, labour input is tied to agricultural poverty and thus cheaply available workforce, capital input is connected to how enticing are alternative business opportunities compared to using capital for land development, and that technology input concerning potato scene in developing countries correlates with or still has largely the form of the knowledge built up locally during centuries of cultivation.

Essay **I** contributed by demonstrating from general economic theory how factor inputs or their prices relate to and are jointly determining product price levels as evidenced in Essay **II**.

Essay **III** provided evidence, through an error-correction model market integration analysis, for presence of food price speculation of noticeable scale in the capital city area in India, since this central area was slower in its price integration comparing to other studied markets.

Essay **IV** found, through its proposed speculation detecting framework which based on RWGCT between prices and arrival quantities, using data of Delhi wholesale markets, that most of the time statistically significant causality existed neither from prices to arrivals nor vice versa, confirming the assumed perfect competition in Delhi wholesale market for potatoes. Divergences, i.e. causal periods, also existed. The most enduring causal periods were due to speculative demand during the food price crises, 2007-2009 and 2011-12, when generally increasing speculative liquidity increased food prices and also speculative potato demand. Thus, a tool based on RWGCT was proposed to locate where assumed perfect competition fails and unexpected, speculative demand or supply shift initiated periods are detected.

Essay **V** tailored a Bayesian regime switching model to forecast monthly potato retail price changes in Delhi.

Table 4.1: Previous studies, comparative research base or main findings, and contributions in Essays **I-V**

Previous study	Comparative research base/findings	Essay	Contribution
Smith (1904, (1776)); Senior (1965, (1836))	Factor prices determine product prices + knowledge receives factor payment	**I**	Mathematics supporting Essay **II** results by economic theory
Smith (1904, (1776))	Factors of production: theory	**II**	Data dimension reduction discovery
Bai et al. (2015)	No precedent, but similarly GDP path	**II**	Paths of factor accumulation found
Caselli (2005)	No precedent, but similarity in results	**II**	1/2 potato price variation explained
Scott (2002)	Potato supply constraints in surveys	**II**	Empirical relation to input factors
Ó Gráda (2001)	Error correction models may detect speculation from market integration	**III**	Detection of weakly integrated potato markets in Delhi area
Robles et al. (2009) and Timmer (2009)	RWGCT attempts to locate food price speculation in time series using conventional 5% risk level	**IV**	Framework to detect financial demand and supply side speculation using RWGCT
Tsai (2018, 2019)	RWGCT result between housing prices and transaction volume with low-frequency data and 10% risk level hints at speculation	**IV**	RWGCT locates speculation in Delhi high-frequency potato price and arrival quantity data, using 5% risk level & robustness checks
Chandran and Pandey (2007)	Seasonal ARIMA for forecasting Delhi potato prices	**V**	Tailored Bayesian regime-switches improve forecast error structure

4.4 Potato related policies

The potato needs less water and smaller land area compared to other major crops. Thus also, as we expanded current trends concerning foreseeable future ahead of us at the start of this thesis, its importance continually increases in the feeding of the developing world. Policy-makers would be wise to step up efforts in the direction that secures the availability of affordable potatoes and sustainable farmer incentives in their country.

Potato cultivation subsidies needed depend on country situation, and Essay **II** results help in assessing country specific needs for sustainable factor accumulation and the order in such efforts. Infrastructures targeted specifically for the potato are central in improving potato importance and the efficiency in factor input use. Publicly provided roads to production areas, communication channels, electricity and cold storages help growers but also lower potato price volatility and related risks of potato merchants, leading to lower marketing margins, bringing a greater share to its poor producers, while also providing affordable potatoes for the urban poor.

The policy-maker should also be aware that increasing the potato's cross-border trade lowers price volatility and evens out price differentials between areas, which may thus lead to increasing or decreasing potato price levels in individual areas. Increased trade also affects farmer incentives in these two directions depending on whether potato is net imported or exported. Even with possible short run pains, opening borders for potato trade is a good idea for the long run. Even one-sidedly removing its border tariffs should be considered as a subsidy in the form of lower prices for the benefit of the poor whereas grower incentives could be compensated through public provision of targeted infrastructures.

4.5 Scope for future work

The following research orientations would add structure and knowledge on the topics we encountered as we studied potato prices in developing countries. Their need and potential benefit was encountered during this thesis research.

Related to Essay **I**, same explanatory shares of factor inputs between cross-border potato prices and income differentials need further exploration for linking growing potato importance to more equitable income distributions.

Related to Essay **II**, unlocking potato importance requires closer work on country specific situations. Countries need usually higher producer prices or more efficient production for producer incentives, and almost always lower final consumer prices. Local bottlenecks preventing increases in efficiency and inputs use should be cleared. This orientation should be done country-by-country, together with determined research result oriented policy as well. Concrete advances in potato importance in developing country conditions should result from local field tests taking into account these potato production related factor inputs specifically for sustained long-term accumulation.

The obtained dimension reduction result which identified classic factor inputs from real world data calls also for harmonising the field which focuses on factors of production and their payments. The work should include classifying earlier wide research which operated at lower levels of abstraction, i.e. defining elements included in e.g. land input, for agricultural and also other produce generally, not just the potato.

The results of Essay **II** also call for developing and applying other methodology and measures that relate to the use of factor inputs in production which principal component scores explored in this research. Such endeavours add benefit to above research orientation for country specific insights and also to harmonising work on general classifications, both relate to factor inputs and payments.

Continued work focusing particularly on India holds a great potential due to grandness of its developing problems but also due to its precursor potential in achieving a staple potato status through furthered subtropical cultivation. The potato in China has in recent decades received boost from unlocking the potential of its factor inputs use, much confirming the main findings in Essay **II**. While India arguably would benefit from higher producer prices for its potato grower incentives, comparing to China it has also extra constraints hindering potato cultivation and use. Storage systems suffer from hotter climate; the use of capital and technology inputs to potato production and storage are highly needed. Typically to many developing countries, where the potato – being cultivated in colder climate of elevated production areas – is locally cheaply available nutrition during the harvest time, wide seasonal and also within country variability in Indian prices remain due to bottlenecks related to sub-tropical and tropical climate. Work still remains to be done to better infrastructure in storage, communication and transportation, although these critical measures have greatly improved in recent decades. Still, the wedge between producer and consumer prices is wide and actions which stabilise prices and lower potato holding risks would be beneficial; these considerations lead into the study of Indian potato market mechanisms, below we expand their potential and need.

Related to **III**, and its study of Indian potato market integration, such studies that open up views to market integration and price transmission, or reasons to within-country price variability generally, are recommended especially for other developing countries having bottlenecks in transportation and efficient storage. Finding the Delhi area special in its price integration, another important obstacle opened for potato research; speculation which widens price fluctuation and overshooting, increasing and making less predictable also consumer prices. Thus, price analysis was continued further in Essays **IV** and **V**; their research potential is expanded next.

Related to **IV**, where RWGCT between Delhi wholesale potato prices and arrival quantities located unexpected, speculative supply and demand shifts; especially markets in developing countries where perfect competition is a natural assumption are potential beneficiaries of such studies. In this case the chosen wholesale market with its informed traders provided needed ingredients. The results are potentially beneficial also more generally, they may essentially deepen our general understanding of the financial market mechanisms and their modelling. Related to **V**, such forecast models of potato prices, especially for developing countries and their markets with wide price fluctuation, add knowledge on components of price behaviour, and also prepare tools for successful organisation of countering socially harmful effects related to price overshooting.

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Articles

This thesis consisted of the present review of the author's work in the field of potato prices in developing countries and the following selection of the author's publications:

ARTICLE I
O. Salmensuu, "Potato importance for development focusing on prices," *Journal of Risk and Financial Management* **14**, 137 (2021).

ARTICLE II
O. Salmensuu, "Macroeconomic trends and factors of production affecting potato producer prices in developing countries," *The Journal of Developing Areas* **55**, 91–105 (2021).

ARTICLE III
O. Salmensuu, "A potato market integration analysis for India: Speculation in Delhi slows price integration," *Review of Market Integration* **9**, 111–138 (2017).

ARTICLE IV
O. Salmensuu, "Speculation in Delhi potato wholesale markets, 2007-2019: Causal connections of prices and arrival quantities," *Cogent Economics & Finance* **8**, 1821997 (2020).

ARTICLE V
O. Salmensuu, "Potato price forecasts in Delhi retail from Bayesian regime switching," *Advances and Applications in Statistics* **53**, 731–770 (2018).

Throughout the overview, these papers were referred to by Roman numerals.

ARTICLE I

O. Salmensuu, “Potato importance for development focusing on prices,” *Journal of Risk and Financial Management* **14**, 137 (2021).

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Article

Potato Importance for Development Focusing on Prices

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Abstract: This paper studies potato prices and consumption in the progress of economic development. Potato status tends to evolve from a luxury to a normal and, lastly, to an inferior good. In the developed world, where the potato thrived and became a food for the poor, prices of the inferior potato attract little interest due to general welfare, which further complicates discerning economic effects by computation. Contrarily, in many developing countries, due to supply constraints the potato is a relative expensive, non-staple, normal good, with little social significance. Whereas it is a common misconception that tastes in developing countries differ from advanced economies, low incomes, together with relatively high potato prices, present a real and obvious hindrance to wider potato use among the poor in the underdeveloped world. Local regressions on FAO data reveal empirical advantages favoring potato price system research in developing countries, more likely yielding predictable, statistically significant, unbiased results. Correct policies could increase potato importance in developing countries and stimulate sustainable and pro-poor growth where consumers receive affordable potatoes, while also producer incentives for greater productivity improve. Furthermore, potato-led research presents widening potential into also understanding general social structures of underdevelopment as similar factors explain both cross-border incomes and potato prices.

Keywords: inferior good; Giffen good; potato; food prices; developing countries; historical development

JEL Classification: O13; O40; Q01; Q18; N30; N50; N90

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1. Introduction

1.1. Aims and Contribution

For many people inhabiting the present-day developed world, the potato is a staple food item, so common that often its importance and everyday use remains unnoticed or is superficially attributed to different tastes compared to low levels of use in developing countries. This essay demonstrates with available data from recent decades that the potato tends to evolve with development from a luxury to a normal and lastly to an inferior good, unifying earlier literature on the subject. While also contributing some ideas on the discussion of input factor costs and output prices, it also introduces potato prices particularly in areas of underdevelopment as an ideal separate research environment for finding solutions that hold potential for generalization into fields that are less approachable empirically due to computational limitations.

1.2. Divide between Developed and Developing Countries

According to (Salaman 1987, Chapter xxiv, pp. 434–45), the potato started as a luxury good in Europe, its major base of dissemination. But due to success in cultivation and promoting its use amongst the poor, it became, passing quickly through the normal good status, eventually a staple inferior good in Europe. In Europe, by the 19th century, the potato arguably was the chosen food of the poor, a driving engine for economic expansion and rise of welfare in general. Also elsewhere, the potato helped nutritional needs and supported city growth, thus inducing development by giving birth to diverse resources of human capital (Bertinelli and Zou 2008; Nunn and Qian 2011; Scott and Suarez 2012b). Rising incomes have led to a more diversified food consumption and declining potato use in richer countries, as is well known, which is understandably causing confusion in potato status related preconceptions of present-day people. Many people inhabiting the developed world consume potato as a major staple food article with an erroneous belief that lower potato use in developing countries is due to differing tastes, but the real reason for differing potato use patterns is related to prices. Historical potato status developments in western temperate countries where potato thrived have also weighed on research settings (Reader 2009; Scott 2002; Scott and Suarez 2011; Walker et al. 1999). Historically, the potato was highly important for social and economic development, particularly for the poor. Potato prices also peculiarly conform to Giffen paradox in economics textbooks, although it is doubtful whether the potato could fit into such a scenario where its rising price forces the poor to increase their potato consumption. Nevertheless, in many presently emerging economies, the potato remains a normal good, and its consumption is increasing, usually with income, as diversifying in eating habits generally occurs from local staple food articles, usually rice, wheat, or maize, towards the less common and frequently more expensive potato (Pandey and Sarkar 2005; Waid et al. 2018).

2. Literature Review

2.1. Theories for Two Main Paths in Potato Status Evolution

Separating the status of the potato between the two common alternatives, an inferior good or a normal good (even near luxury food item), and implications of these two for potato prices and development are central themes of discussion in this paper, also below in related economics history, i.e., attempts to formulate a general theory on the evolving importance of potatoes with regard to advances in national income levels. Whereas historical observations from the West in its way from poverty to economic success fueled by potato nutrition allowed no general model of historical evolution in the potato use with respect to income level, the two viewing angles may be unified basing on different potato statutes in consumption; a luxury, a normal, and an inferior good.

A principle that describes the evolving importance of potatoes and cereals, that fits into the economic history of the western temperate countries, appears in (Bennett 1936, 1941, particularly pp. 41–42 in the latter one), basing on relative prices of calorie-content of the nutrition. Poor regions depended heavily on potatoes (and other 'cereal-potato' foods; corn, rye, and barley), shifted to wheat as incomes rose, and, finally, with still further increases in income, shifted still further away from potatoes and cereals (including wheat), adding dependence on other foods (e.g., sugar, milk, meat, fruits, and vegetables). Based on the above Bennett's principle, a descriptive model that connected society advancement level to its potato and wheat use was presented in Gray et al. (1954). Variability due to climate and preferences also explains cross-country differentials in the importance of potatoes and cereals in nutrition, but, according to the model, all countries that started with a 'potato economy' would follow roughly the same transitional path, finally reaching a developed economy where neither potatoes nor wheat are emphasized in the diet. Walker (1994) augmented the descriptive model to have total potato consumption subdivided into fresh consumption, processed foods and animal consumption, although, according to Scott (2002), its feed share appears too high since, in today's developing countries, the potato is usually a cash crop, too expensive to be given to farm animals, unlike the history of present-day developed countries. Compared to earlier research an added contribution in the augmented model was that potato consumption would also increase in late stages of economic development because of the increase in processed food demand. Poleman and Thomas (1995) grouped the potato together with other starchy staples for international comparisons of income and dietary change. Basing on its indications, Walker et al. (1999, p. 44) presented conditions for a descriptive model which presents the approximate historical path of potato consumption behavior of modern western developed countries where the potato is now usually an inferior good. This temperate world historical potato consumption development pattern towards an advanced economy, although a past times candidate for universal applicability, works no longer in the majority of present-day developing countries; rather than being a staple, the potato is usually an expensive crop with low consumption share mainly due to constraints on the supply side (Scott 2002; Lal et al. 2011; Devaux et al. 2014). Thus, the potato groups poorly with starchy staples in such comparisons for income and dietary change. In addition, Asian countries are experiencing changes for starch demand through new uses even though incomes rise, possibly restricting Bennett's principle (Fuglie 2004). Japan, Hong Kong, and Singapore were shown as outliers already in empirical observations of Poleman and Thomas (1995, pp. 152–53). In any case, the potato differs markedly from other starchy tubers in developing countries. Per capita consumptions for cassava and sweet potato are decreasing with per capita income, while per capita consumption for potato is increasing with per capita income in cross-country comparisons (Scott 2002, p. 50; also see Figures below, in this paper). In summary, research points out two main potato statuses in present-day developing countries; first, the much more common, a non-staple normal good, and secondly, the rarer but of great historical importance, e.g., in supplying also for North European countries' world dominion during colonial times, a staple inferior good (De Ferrière le Vayer 2017; McNeill 1999).

The usual role of the potato in developing countries of present-day, however, differs from that of historical Europe described above. Nevertheless, also in Europe, the potato initially started as a luxury good, and its status more or less gradually evolved into an inferior good through the normal good status. Similarly, in many developing countries where the potato is now a non-staple normal good, having entered into the diet at a later stage of development in the form of higher priced low consumption share vegetable (Walker et al. 1999, p. 42), welfare increases may eventually turn it into an inferior good, provided that welfare spills also to the poor masses and price incentives for its cultivation improve. In that sense, all countries do follow, in a grand outline, a similar potato status trajectory from a luxury to a normal to an inferior good, but this process is often slow, stalls easily, and even periodically retreats, depending on changes in country specific conditions, as we will also explore using FAO data.

Giffen Property

In European history, potatoes were an inexpensive staple food for the poor, also often an inferior good, decreasing in consumption as incomes rose. And in economics literature, the potato goes infamously still farther by being the usual textbook example of the dreaded Giffen attributes which are forcing the poor to abandon complementing foods and increase potato consumption as its price rises. The wide circulation of Giffen property for potatoes, which become the best popularized of its price action in academic circles, received its first ingredients from Alfred Marshall's mention of bread having such attributes for the poor in the third edition of his Principles of Economics (Marshall [1890] 2013) and became completed as Paul Samuelson upgraded the story by choosing instead the potato and the mid-nineteenth century famine in Ireland (Samuelson 1964). This Giffen potato example is widely contested outside popular textbooks since it is unconfirmed by available data and common sense; the poor could not possibly consume more potatoes as their prices rose in famine conditions since less potatoes were available due to the blight that devastated Irish potato crops (Dwyer and Lindsay 1984). Even though potato crop casually failed, the potato was arguably the chosen food for the poor, and one of the major driving engines for the economic expansion and generally rising welfare in Europe from the 19th century onwards. Rising incomes then have led to lowering potato shares and more diversified food consumption.

Potato-dependent historical Ireland of the famine years was chiefly suspected for Giffen behavior in potatoes, but gathered evidence speaks against it, as well. Dwyer and Lindsay (1984) argued that the potato was not a Giffen good during the Irish potato famine of the

1840s, and even more generally that a closed peasant economy engaged in subsistence farming is a wrong place to look for Giffen goods, potatoes or any other, and suggested instead Singapore, a poor community that imports most of its food. Kohli (1986) responded by arguing that a closed economy also could exhibit Giffen behavior but, instead of potatoes being Giffen goods, suggested at looking at meat. Then, Davies (1994) argued that the Irish famine represented Giffen-type response on potatoes but no actual Giffen behavior as food prices were increasing generally. In a recent study, Giffen-style behavior was found in bacon pigs of the Cork market at and around Irish famine, whilst potatoes, wheat, barley, and oats displayed normal good characteristics during this period (Read 2017). At times of food insecurity, it is indeed sensible that an inferior good turns into a normal good, effectively ruining the theoretical approach which assumes constant utility.

The theoretical debate extends also to concern the influence of initial price levels or consumer endowments. Dougan (1982) modeled unstable, final equilibrium price to be dependent on the point where trading starts. This point, in turn, affected the modeled probability for Giffen behavior which was generalizable from a single household to concern the aggregate demand curve. Berg (1987) argued that the theoretical definition of Giffen's paradox ignoring the initial endowments of the consumer is ambiguous, whereas Nachbar (1998) criticized analysis which bases on fixed income demand as potentially invalid. Davies (1994) incorporated a calorie-modified utility function to explain Giffen behavior in decision processes compelled by a constraint on the level of subsistence, as classical writers also might have emphasized. Jensen and Miller (2008) reported experiments which uncovered Giffen behavior for rice and wheat flour in China. According to the study, inferiority and also Giffen behavior in basic foods are more likely to be seen in the purchases of those individuals who have escaped the utmost poverty of the society. Doi et al. (2009), by presenting a suitable utility function, concluded that Giffen behavior was independent of income share of the inferior good and could be found in all income classes, not only for the poor.

The Giffen effect requires that the potato should be an inferior good without near substitutes, and a great part of consumer income should go into potatoes, and at least some of it into a normal complementary good, such as meat. Then, rising potato price would increase quantity consumed, i.e., the demand curve would slope upwards, which would violate the law of demand. If the potato is so inferior that the income effect is greater than the substitution effect, potato price increase would lead the poor consumers to buy more of it and abandon meat. Despite wide use of this example in economics textbooks, no empirical research evidence exists for the Giffen behavior for the potato. In most developing countries of today, the potato is a normal good. Thus, the search for Giffen potatoes should focus on countries where it is an inferior good; but, in countries where it is an inferior good, it likely has near substitutes which neutralize the potential for Giffen property.

3. Materials and Methods

3.1. Prices, Consumption Shares, and Incomes

FAO data allows comparing how potato producer prices, consumption measured as calorie share, and income development relate to each other in present-day societies, using averages from the first two decades of the 21st century to detect directions of change for each individual country or area. For varying research settings, averaging over 10-year data periods appears promising as it sidesteps difficulties that ensue from short-run variability in prices and production quantities (Rana and Anwer 2018; Salmensuu 2021; Scott and Suarez 2011). In this research, we will study potato price, consumption, and income data for countries and areas using their decade-mean moves and cross-sectional positions.

Figure 1 relates potato price and consumption share by income classes. Countries may be classified by prevalent data clusters regarding their potato producer prices, consumption shares, and national GDP incomes. Mediocre income countries averaged the 2000s between 7.35 and 9.65 in natural logarithm of per capita GDP using inflation adjusted 2010 dollars.

Markedly, higher price usually means lower potato consumption share, and higher share lower price. In the long run, no country has both high share and high price, but, especially the poor developing countries, may have—due to limits in general purchasing power, distant producing areas, lacking infrastructure with high freight and storage costs, and weak terms of trade of the potato producers—low (producer) price with low (often predominantly urban) consumption share. Most countries in the FAO data had consumption shares varying between 0.017 and 0.055, and, in this mediocre range, the producer price appears to be generally higher in richer countries, whereas the lowest share area also reveals a similar view. The poorest countries often suffer from a wide differential wedge between producer and consumer prices, which leads to low potato producer prices together with low consumption share.

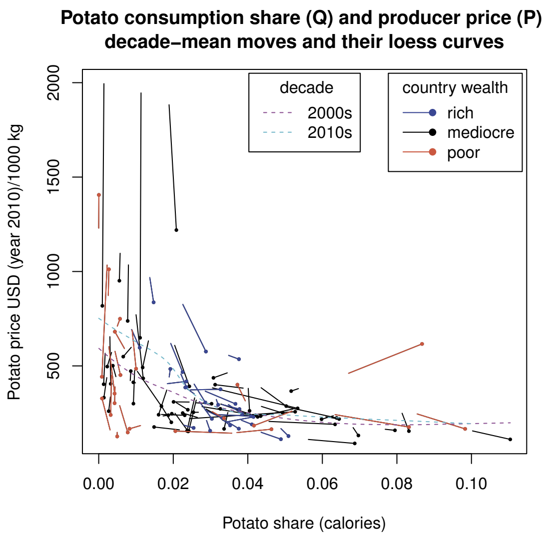

Figure 1. Potato consumption against price. Each country is represented by a half open line segment (pin), endpoints representing data values. The closed end (pinhead) of each connecting line is average for 2000–2009. The open end (without pinhead) is average for 2010–2019. The segments (pins) are colored here by three classes of GDP per capita.

3.2. Research Questions

We will next inspect using recent decade averaged FAO data from 2000s to 2010s the two views for potato status evolution; an inferior good following a predominantly historical pattern for temperate western countries as opposed to a normal good for a majority of present-day developing countries in subtropics and tropics. We are interested in analyzing how they match to each other in the data and how they fit into a unifying view. Particularly, by using comparative statics results (Chiang 1984, pp. 215–17 derives the normal good case), we will separate dP/dY and dQ/dY by their signs, i.e., whether these shifts are positive or negative sloping, and then consider cross-sectional local regressions on this endpoint data of decade-average moves for hints how likely statistical modeling can succeed in distinguishing empirical effects.

3.3. Comparative Statics: Inferior and Normal Good Potato Statuses

Mathematics below can demonstrate the intuition how development affects consumption and prices depending on two general potato statutes, either an inferior or a normal good. Following Chiang (1984, pp. 215–17) suppose a market where potato quantity demanded equals supplied quantity in equilibrium, so that $Q_d = Q_s$. Quantity supplied is a (supply) function S of price P; thus, $Q_s = S(P)$. Naturally, supply is increasing with price, i.e., $dS/dP > 0$. Quantity demanded is given by a demand function D of price P and income Y; thus, $Q_d = D(P, Y)$. Demand is decreasing in price (no Giffen behavior here), i.e., $\partial D/\partial P < 0$, while the potato status commands the direction of $\partial D/\partial Y$. For the inferior good status of the potato, we have $\partial D/\partial Y < 0$, whereas, for the normal good status, on the contrary, it is true that $\partial D/\partial Y > 0$. The equilibrium price $\bar{P}$ is a function of the only exogenous variable Y; thus, $\bar{P} = \bar{P}(Y)$. In addition, in the equilibrium, we have the corresponding equilibrium quantity $\bar{Q} = Q_d = Q_s = S(\bar{P})$.

Applying implicit function theorem gives $\frac{d\bar{P}}{dY} = -\frac{\partial D/\partial Y}{\partial D/\partial \bar{P} - dS/d\bar{P}} > 0$, where the last inequality holds using above assumptions for a normal good status, whereas, for an inferior good status of the potato, contrarily $\frac{d\bar{P}}{dY} < 0$. By the chain rule and recalling that $\frac{dS}{d\bar{P}} > 0$ and that $\frac{d\bar{P}}{dY}$ was just solved to depend on the two statuses, we also receive the corresponding result that concerns the equilibrium quantity: $\frac{d\bar{Q}}{dY} = \frac{dS}{d\bar{P}}\frac{d\bar{P}}{dY} > 0$ for a normal good, and $\frac{d\bar{Q}}{dY} < 0$ for an inferior good.

Thus, by the above mathematics, for the normal good status of the potato, increases in its price and quantity associate with income growth; for inferior good status on the contrary, its price and quantity decreases associate with income growth. We will use these results in quantifying how FAO-areas by their cross-sectional positions match to their last decade-average move direction from the 2000s to 2010s. Compared to rich countries, poorer countries are more stable in inferior or normal good trajectories and have larger variability in potato prices and consumption levels. Such characteristics aid in distinguishing effects in quantitative research.

4. Results and Discussion

Whereas in richer countries where affordable potato nutrition is abundantly available, and the diversification in consumption habits made the potato an inferior good, statistics demonstrate that, in modern-day developing countries, the diversification is due to income rise also, but its general direction is opposite, towards the relatively expensive and little used potato. Thus, in developing countries, higher potato consumption shares follow as incomes rise.

Figure 2 presents how prices and growing incomes relate to each other by their recent decade-average moves, whereas Figure 3 represents income against consumption share that approximates consumed quantity. A normal good by its definition receives increasing demand with income, $dD/dY > 0$, whereas the opposite is true ($dD/dY < 0$) for an inferior good. Chiang (1984, pp. 215–17) demonstrates for the normal good condition that, holding everything else constant, increasing income also leads to increases both in price, $dP/dY > 0$, and in quantity, $dQ/dY > 0$. For the inferior good condition, $dD/dY < 0$, increasing income then trivially leads to decreases both in price, $dP/dY < 0$, and in quantity, $dQ/dY < 0$. Positive or negative slopes of these moves (drawn as pins, similarly as in Figure 1), thus, convey normal or inferior good status, respectively, in Figures 2 and 3. In all the three Figures alike, we notice that as incomes rise both potato price and share are increasing particularly for countries of lower GDP. This phenomenon indicates the potato's usual normal good status in developing countries. Figure 2 also illustrates that potato consumption share tends usually to be mediocre in richest countries, with few low consumption share classified countries in the high-range of GDP. Cross-sectionally, low share countries have usually higher producer prices with an increase in prices and shares until the mid-range of GDP. Particularly, we notice that, for the poorest countries, cross-sectional movement directions in potato status depicted by the local regressions are generally aligned with the individual country movements, whereas the situation is more blurred for more developed countries. Thus, whereas less developed countries more clearly follow their expected status that relates to their position with respect to the coordinate axes, richer countries are more prone to behave irregularly and move opposite to cross-sectional position related patterns in inferior or normal good statuses. This phenomenon understandably causes modeling problems unless developed and developing countries are differentiated.

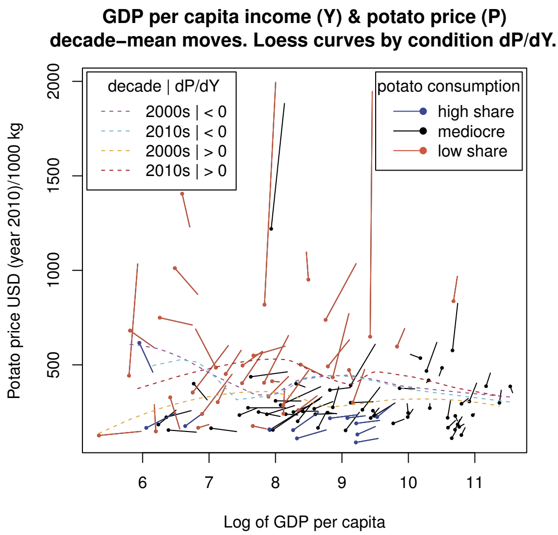

Figure 2. Logarithm of GDP per capita against potato producer price. Richer countries have less separable potato price behavior with respect to income, and weaker predictability as cross-sectional positions followed by local regression curves weakly if at all agree with potato statuses in individual country moves. For the poorest countries, the slopes (dP/dY) of the latest decade-mean moves are a better match to the signs of the slopes of cross-country local regression curves of the 2000s and 2010s. The slopes optimally rise for a normal good and descend for an inferior good status of the potato, aiding cross-sectional modeling.

Producer price data for potatoes is relatively scarce in FAO statistics, and we will double the number of areas studied by ignoring its absence. As potato consumption share relates to potato price, as we saw in Figure 1, it is possible and also more interesting to continue the study including this other half of potato related observations, although they are missing actual price data. Thus, the remainder of this study discusses potato consumption share against GDP per capita. Figure 3 relates that, especially for less developed areas, potato consumption share tends to increase with rise in GDP per capita, whereas, for richer areas, increasing GDP often leads also to lowering of potato consumption share. It also seems that a turning point exists where increased development can make the potato an inferior good but—counteracting this inferior good trend—refined uses which appeal to wealthier people will emerge with development; noticeably, richest areas do not have very low shares. With similarity to our earlier observation in Figure 2, we notice here also that, for developing countries, the signs of the drawn slopes in individual FAO-area data are consistent by the condition dQ/dY cross-sectionally in local regressions. On the contrary, for the richest countries, the local regression curves are rising where they use endpoint data consisting of descending decade-mean moves and descending where they use data consisting of rising move endpoints.

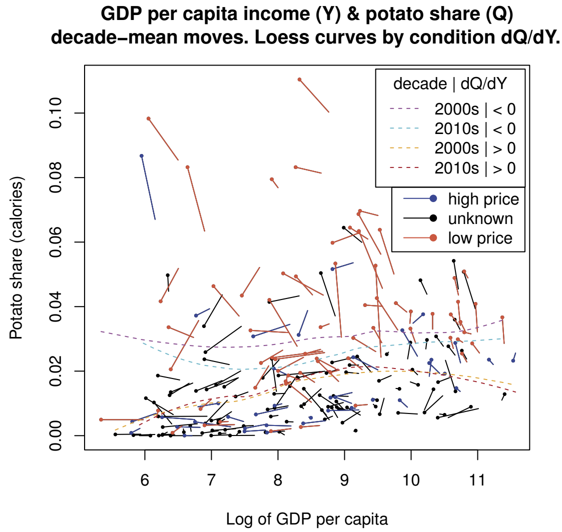

Figure 3. Potato share against GDP per capita. Half of the FAO-areas with unknown producer price data. The limit of 350 USD/1000 kg, using inflation adjusted 2010 dollars, classified known potato prices into high or low for this representation. Developing countries are consistent to their individual country condition dQ/dY in cross-sectional local regression slopes, whereas rich countries cross-sectionally behaved contrarily to their individual country conditions with loess curve rising for descending decade-mean move endpoint data, and vice versa.

Figure 3 also presents that, in many poorer areas, potato consumption share slowly trends upwards together with development. We should also observe that half of the areas, a notable minority of low income developing countries, as well, fit into inferior good potato status by decreasing share of potato consumption with increasing welfare. Particularly, in the richest countries, the potato is often viewed as an inferior staple that faces per capita consumption decline with rising incomes as consumers diversify their nutritional habits. The variance in consumption shares is high for poor countries and low for rich countries, which is unsurprising as poor countries that have either a normal good potato with a low consumption share or an inferior good potato with a high consumption share converge in their potato status paths with development. Simplifying, we seem to have areas, where potato is inferior and areas where it is still a normal good. Refined end-uses may make its path change—from an inferior good status back to a normal good status—at later development phase of the society, while areas where the potato is a low share luxury or normal good may gain share rapidly with success in cultivation and turn potato into an inferior good. In the European history, the potato followed such a route. In addition, in Asia, the potato was a luxury good, e.g., in Pakistan and Bangladesh, still in the 1970s and 1980s (Bouis and Scott 1996).

4.1. General Stages in Evolution of Potato Importance

As half of the FAO-areas in Figure 3 represent inferior good characteristics by their $dQ/dY < 0$ condition, while the other half follow normal good characteristics where decade-mean moves conform to $dQ/dY > 0$, we discuss shortly inferior and normal good potato statuses' relation to development.

Considering the evolution of potato importance as stages, the first stage belongs to luxury good status; potato consumption and production are low, and consumer price is particularly high. In Figure 3, these characteristics are particularly identifiable from lower income countries with low potato consumption share. High priced potato belongs mainly to the diet of the wealthier people (Salmensuu 2021; Scott 2002; Thiele et al. 2010). However, high potential unit profits in the supply chain of luxury good potato likely lead to engineering of increased supply which progresses the potato to its normal good phase. Or even farther, since even though the potato was luxurious initially after its arrival to Europe also (Salaman 1987, Chapter xxiv, pp. 434–45), it claimed—after initial scepticism—its place as a significant staple food item and an engine of economic growth, which transformed it into an inferior good.

The second of the stages belongs to the normal good status, which supply constraints (Kaur et al. 2020; Salmensuu 2021) make an enduring, stable stage in present-day developing countries as the potato is increasingly used as a vegetable crop with economic development; in these countries advances in economic development are accompanied by increases in potato use, although prices also rise with increasing demand as the potato becomes affordable to many (Chiang 1984; Salmensuu 2021, and Figures of this research). As the poor people gain in income, they start using the potato. Still, Scott (2002, p. 51) suggests that per capita consumption in many developing countries may never reach that of Europe. Many developing countries need persistent efforts in research based policy for the potato to become a staple food article, price risk is a noted constraint to its expansion (Guenthner 2010; Pandit and Chandran 2011; Salmensuu 2020). Progressing into a staple food article in the case of the potato has often been accompanied by general positive wealth, welfare and health effects in population. These effects were first quantitatively established in Nunn and Qian (2011) and expanded to study common effect from the potato and milk in Cook (2014), since milk with its high vitamin A and calcium content provides complementarity to potato nutrition. A subsistence farmer only needs daily intake of 5 potatoes complemented with a quart of milk to remain healthy. We also notice from relative country-level aggregate statistics of the latter study that Chinese have weak lactase persistance which makes the potato, with its milk complement, nutritionally more valuable to Europeans. Although the Chinese during colonial times in large rejected introductory attempts of many European values and customs, including Christianity, democracy, and potato cultivation, their recent science based policy has been able to notice and correct some of the errors, at least the one concerning the potato (Su and Wang 2019). Potato cultivation enjoys high suitability in some parts of China, where its benefits are now experienced and it is slowly heading to become a staple food article. In some more remote production areas, the potato is already a local staple, which is usual for developing countries, also more generally (Khanal et al. 2019; Scott and Suarez 2012a). In Figure 3, the normal good status for the potato is found particularly in less wealthy countries where increasing income still increases potato share; reaching the staple status often means advancing wealth and inclusive welfare, but then also lowering consumption share eventually entails as the potato has transformed into an inferior good.

The third stage is the inferior good. This common potato status in rich countries has led also to two misconceptions in the building of theories related to evolving potato importance. Firstly, the potato is the dreaded Giffen good of many economics textbooks, although no evidence is encountered of such potato behavior. Secondly, some studies make no differentiation between developed and developing countries, although both empirical modeling and historical circumstances would mandate it. The poor ate potatoes as a basis of their diet in temperate western countries as these countries transitioned into the developed world, whereas, in the contemporary developing world, the potato is food for more affluent people as supply constraints hinder its cultivation incentives.

Where the potato is a major staple, it is bound to become an inferior good also. With more income, poor consumers are diversifying their consumption habits, away from the potato. Europe, that accounted for 4/5 of worldwide potato area and production half a century ago, now accounts for 1/3 of area and 1/2 of production (Nayar 2014). In this inferior good group, the potato is currently a cheap staple, usually with declining per capita consumption and large spatially clustered production. This tendency applies to modern developed countries that have evolved in their history from a potato economy as approximated by the Walker et al. (1999) descriptive model but also to some countries that lag in development and experience persistent farmer poverty despite high potato use, such as Peru (Antazena et al. 2005; Mayer and Glave 1999; Rose et al. 2009). Losses experienced by peasant producers narrate that Peru, the origin of the crop, is also on its way towards spatially clustered commercial production. For the developing countries, such production and consumption characteristics are rare, perhaps best approximated in the Andes and a few former Soviet states. As another example of such high share countries, Belarus tracks the aforementioned historical descriptive model (income growth reducing potato consumption) which needs that potatoes can be seasonally grown over large areas and that they can be a staple food crop. Their relative weak development even in the midst of potato plenty still favorably compares to countries that have lacked potato blessing and experienced similar political turbulence.

With enough income growth, an inferior food item is bound to lose its share in consumption until it is no longer a staple food article. The latest decade-average moves in Figures 2 and 3 have positive slopes in many of the richest countries, however, thus unexpectedly demonstrating normal good characteristics in potato use. Such renewed interest for the potato in rich areas due to new uses does follow Walker (1994) description. Ensuing lowest variance in consumption shares for potato markets in richer areas also makes distinguishing their determinants harder compared to poorer areas where also expectedness in trends how potato status associates with development presents a better structure for computation, including areas where potato is already an inferior good.

4.2. Long Run Averaging, Factor Prices, and Development Research

Above, we concentrated on studying associations of potato prices and consumption using decade averages, which appeared in poorest areas to favor empirical research. The same may be, in all likelihood, said on the other parts of the potato price system, extended to factor prices, as the mathematics below convey.

Consider familiar supply and demand identities from economic theory:

$Q_s = S(P, F_p)$,

where Q_s is quantity supplied, which is determined by a supply function S of price P and input factor prices F_p;

$Q_d = D(P, Y, R_p)$,

where Q_d is quantity demanded, which is determined by a demand function D of price P, income Y, and substitute (and complement) pricing R_p.

In equilibrium, quantity supplied equals demanded quantity, i.e.,

$Q_s = Q_d = Q$.

Assuming that Q and P are endogenously determined, the exogenous variables, Y, R_p, and F_p, determine their equilibrium levels;

$Q = f_0(F_p, Y, R_p)$,

$P = g_0(F_p, Y, R_p)$.

In macroeconomic scale (production and income are nation-level), we can also present the latter function g_0 of price using instead Equation (1)

$$P = g_1(F_{use}, Y, R_p), \quad (1)$$

since F_p, i.e., factor prices of inputs (land, labor, capital, technology), are likely inversely related to their utilization F_{use}. Furthermore, as relative prices of substitutes, R_p, correlate with the importance of the potato in a society, what is presented above agrees with the data dimension reduction results for developing countries (Salmensuu 2021) where, in addition, market infrastructures affect to both demand and supply sides. Such infrastructures targeted specifically for the potato are a key ingredient to greater potato importance, greater effectiveness in the use of its factors of production, and increased supply of potatoes to urban centers, while increasing the profit share of the farmers.

Another point of view particularly highlights the effects of potato supply side constraints to factor input use. Classical period economists usually assumed prices to depend on the cost of production, i.e., the supply side. In the long run, the supply was perfectly elastic. Its intuition may be followed by setting competitive markets with zero profits in Equation (2), so that income is equal to costs—alternatively, assuming inputs receive all payments, the same Equation is an accounting relationship independent on technical or allocative efficiency of the produce (Dias Avila and Evenson 2010). Thus, using above notation, let F_{use} and F_p denote vectors which take input use and price values such that $F_{use}^T = (x_1, x_2, x_3, x_4)$ and $F_p^T = (p_1, p_2, p_3, p_4)$, where the superscript T denotes a transpose. In equilibrium, then:

$$PQ = F_p^T F_{use}. \quad (2)$$

However, typical, also more generally, to agricultural commodities, prices and quantities are usually in a cobweb cycle where farmer decisions are also sensitive to changes in relative prices to other produce, with losses and profits to farmers alternating. Thus, in practice, long run averaging is needed for Equation (2) to agree with empirical reality. Whereas, in the short-run, potato production costs and incomes diverge as potato price fluctuation hinders competitive market entry and exiting without losses, long run hypotheses for factor input cost calculations in various levels may be based on local production costs determining output prices for non-traded commodities (Pandit and Chandran 2011; Pawelzik and Möller 2014; Salmensuu 2021).

Equation (2) may be further reduced, noting F_{use} complementarity for constrained supply and an inverse relation between factor prices and utilization, while P and Q are endogenously determining each other, by specifying a function g where potato output price is explained by the use of factors inputs F_{use} or even simply their prices; $P = g(F_p)$. In practice, whether to choose either output levels or prices, and similarly factor input levels or their prices, for empirical estimation depends on availability of data and methodologies. Many sources, including FAO data, provide country-level estimates more often on quantity or consumption share and relatively scarcely on price information for several commodities including potatoes. In addition, methodologies which base on input and production output levels are the mainstream, e.g., popular Malmquist index (Rana and Anwer 2018, applied to potato productivity) non-parametrically differentiates measured productivity into technical and efficiency changes. Its cost-based version benefits also from factor prices (Maniadakis and Thanassoulis 2004). Although more rarely used, prices also can play a prominent role due to the duality between production factors and their prices, which is useful for productivity growth accounting (Hsieh 2002; Jorgenson and Griliches 1967). Prices are easier to observe than quantities that pass through the markets particularly in developing country conditions. Acquiring reliable local estimates which quantify potato trade or production levels or corresponding factor inputs, such as totals in farmland used, working man-hours, investments, or technological inputs for crop production, is likely a challenging task, compared to simply observing the prices that, in competitive markets, relay similar information, while integrating also such supplies in the economy that pass unnoticed from officials. In general, developing countries would benefit from simple measuring approaches instead of estimates based on trade and production levels that pass through the official channels and cumbersome regulations.

Concerning what was noted on the duality between prices and production, and its applications in the total economy, as well as single individual industries, the study of the potato price system appears important to help us understand the wider economy and its development. Characteristics particular to the potato scene in developing countries served as a structure so that the dimension reduction exploration results in Salmensuu (2021) could validate general economic theory presented above for Equation (1). Despite its special focus, similar reasoning should apply to multiple other markets and produce due to the generality of the above theory, including fields of study that are less approachable empirically. It is likely that the potato could show the way forward in research that concerns cross-country income differentials. How macroeconomic factor inputs explain cross-country income differentials compares very closely to their association with cross-country potato producer price differentials. In established reviews of development accounting, capital input accounts for 20 percent and human capital input accounts for more than 10 percent of cross-country income differences, whereas unknown efficiency or total factor productivity has 50–70% share (Caselli 2005; Hsieh and Klenow 2010). Using dimension reduction to construct the factors, (Salmensuu 2021) found similar explanatory shares for these two factors (20 and 12 percent, respectively), whereas also similarly close to 50% of the variation in cross-border potato prices remained unknown. In addition, factors corresponding to labor and land inputs also provided explanation for potato prices, 7 and 12 percent, respectively. Efficiency undoubtedly plays a major role in potato scene, as well. Where factor prices or their rents are high, output costs and prices are also high, and outputs low. Inputs are either idle or inefficiently used without complementarity benefits.

As potato prices and consumption are a key to inclusive growth, and also relate structurally to general income growth in developing countries, the study of the potato price system presents potential for opening insights on such social structures of underdevelopment that are less approachable empirically directly.

5. Conclusions

This work demonstrated through running local regressions and discussing recent research on potato importance for development that we clearly more likely encounter statistically significant, unbiased, correct coefficients and conclusions on the potato price system using data from poor countries compared to the developed world where welfare and highly integrated markets complicate calculations. Particularly, we noticed a difference in stability how inferior and normal good statuses are affected by development. The potato becoming a staple food article has usually led to it passing from the normal good status into an inferior good, particularly as increasing use of potatoes in history often has been accompanied with notable economic growth and inclusive welfare, China being a recent example of the potato induced growth potential (Su and Wang 2019; Wang 2015). With such an established effect on country wealth, it is expected that the study of potato price system can also open insights on cross-country income distribution as the basic factors of production have similar explanatory shares on the two—potato producer prices, as well as income differentials.

We also unified the two views on potato's evolving importance, demonstrating the potato's tendency to evolve with development from a luxury to a normal and lastly to an inferior good. The consumption share behavior of the potato as a society develops may be an indication whether it is an inferior, a normal, or still a luxury good in a developing country, thus affecting its income elasticity of demand as consumption share approximates demand where supply constraints prevail. The potato can be classified through income change affected demand change into luxury, normal, and inferior good statuses. The luxury good stage is usually an initial, unstable situation; high unit profits entice engineering supply usually very soon. The normal good status is the most usual status for the potato in present-day developing countries; this status is also relatively stable due to common and persistent supply constraints. The other stable status for the potato is an inferior good, which is rare for present-day developing countries but it was historically predominant in the development of the temperate western world.

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ARTICLE II

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MACROECONOMIC TRENDS AND FACTORS OF PRODUCTION AFFECTING POTATO PRODUCER PRICES IN DEVELOPING COUNTRIES

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ABSTRACT

The potato, as an affordable and nutritious food, could be a major aid to development. In many present-day developing countries, however, its profitable cultivation and wider use are hindered by supply constraints. For production, a chief problem is in input use conditions, which we here approach via output price level differentials. To explain the cross-border differentials in the producer price of the potato, averaged over a decade, we use principal component (PC) regression. We perform PC analysis on 33 variables of 40 developing countries. We retain the seven most important PC's expecting them to represent factors or trends in the data. Loaded by agricultural and social conditions, the PC's are put to explain potato producer price in linear regression. The basic factors of production, land, labor, capital, and technology correspond to the four PC's that statistically significantly explain potato price. They explain half of the cross-border variation in potato producer price. Studying macroeconomic inputs, we find also likely paths of their accumulation. Land input depends on potato suitability. Labor input correlates with certain conditions, namely those of agricultural poverty, that bring poor terms of trade for small farmers. Capital input, to agricultural land development, is inversely dependent on urban business opportunities. Technology input correlates with human capital or knowledge. Greater input use, through its effects on production, decreases potato price. The three other PC's are macroeconomic trends; economic growth, growing potato importance, and improving market economy infrastructures. Economic growth and greater potato importance may lead to higher potato prices in developing countries, whereas improving infrastructures may lower average prices. Concerning potato related agricultural policies, our results support the view that potato supply constraints, surveyed in literature, prevent effective and coordinated input use in developing countries generally. Efficiency in input use would likely be increased by infrastructures that are targeted specifically for the potato. The results also lend support to the practice of sequentially addressing the constraints, but since they exist due to a high degree of complementarity between inputs, we should prudently consider the order in efforts, and the sustainability of benefits.

JEL Classifications: Q11, Q18, R51, R58, Z12
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INTRODUCTION

Affordable potato price potentially provides major aid for the poor, whereas business incentives require that producers receive a price that covers their opportunity cost of choosing potato production. Combining these two opposing needs, to have them adequately meet, promises greater importance for the potato. Its consumption share and production increase would naturally follow. Inversely, should potato price be too high for general consumption, or too low for producer incentives, the progress can be stalled. Consequently, in attempts to increase the importance of the potato, it is central to understand factors that affect its price.

Earlier research on potato pricing has uncovered relatively small nuances, usually specific to single countries or market areas in the developed world, which are important for competitive local marketing. Another important research literature concerns annual production fluctuation. Here we study neither marketing nor supply responses, but we explore the determinants of the producer price level averaged over the longer run. Including data from developed countries would likely make our efforts fruitless, due to the noise produced by general welfare and the potato's status as an inferior good. Contrary to this, in developing countries the potato serves a favor for the researcher as country borders noticeably maintain the differentials in its price level unlike many other commodities (Morshed, 2007). We will regress the potato price on PC's formed from developing country data and attempt to answer the research question: *What factors or trends in societies are affecting the producer price of the potato?*

According to Sen (1981), food insecurity in developing countries is related to demand side constraints as the poor lack purchasing power and access to food. While this can be generally true, we must have a different view concerning specifically the potato. In developing countries, potatoes are not the usual items for import or food aid due to their perishable nature compared to wheat. The potato became a staple in European temperate countries and supplied them for world dominion during colonial times (McNeill, 1999). Even today, its production in the tropics and subtropics is mostly located in remote high-altitude regions where the soil and climate resemble European fields. Therefore, in accordance with literature on potato supply constraints (for example Scott, 2002, p. 51), our most fundamental theory says that the essential constraints concerning potato consumption, are on the supply side. Thus, we will check that the statistically significant PC's are related to supply side constraints and thereby affect the potato producer price level.

DATA

Statistical data for poor countries mostly comes from the Food and Agriculture Organization of the United Nations (FAO) and Wikipedia internet sites. The selected countries had a potato producer price and were also ranked Low Income Food Deficit or Least Developed Countries by FAO. These conditions supplied 40 poor countries. The data was collected in spring 2012.

Each potato producer price time series for 2000-2009 was deflated by the US consumer price index into year 2000-dollar series. Thereafter averages were taken of these series thus forming the average potato producer price levels for the selected 40 poor countries.

In addition to the potato producer price we have social data from the 40 countries, mainly related to agriculture, that could potentially affect the potato price. In total we have 33 social data variables averaged over the decade or single time point estimates. Table 1 lists them with their units. Variable names, which are presented in later tables, are easily connected to it.

TABLE 1: PC LOADING VARIABLES

	Variable	Unit
1	Share of Christian church membership or identity	%
2	Population density	/km^2
3	Population growth rate	%/year
4	GDP per capita	USD/year
5	Services GDP share	%
6	Human development index	score
7	Total population	millions
8	Life expectancy at birth	years
9	Urban population share	%
10	Undernourished share	%
11	Child mortality	/1000 live births
12	Water use share in agriculture	%
13	Water use share in industry	%
14	Agriculture GDP share	%
15	Agriculture export share of total export value	%
16	Agriculture import share of total import value	%
17	Maize producer price	USD/1000kg
18	Export value per capita	USD/year
19	Import value per capita	USD/year
20	Potato production per capita	kg/year
21	Potato production per agricultural population	kg/year
22	Agricultural land development value per agr. pop.	USD
23	Machines and equipment value in agriculture per agr. pop.	USD
24	Fixed livestock value in agriculture per agr. pop.	USD
25	Plantation crops value per agricultural population	USD
26	Total capital stock value in agriculture per agr. pop.	USD
27	Arable land share of total land area	%
28	Permanent crops share of arable land	%
29	Pastures proportion to arable land	%
30	Irrigated land share of arable land	%
31	Per capita cereal production	kg/year
32	Per capita meat production	kg/year
33	Per capita fish production	kg/year

Concerning the first variable Christianity, we notice that the potato was spread and made known to many countries during colonial times by Europeans together with Christianity; "The potato's global voyage began in earnest in the seventeenth century. Stay-at-home Europeans may have had misgivings about the suspicious new crop, but sailors, soldiers, missionaries, colonial officials and explorers quickly figured out that the potato was a good thing to carry to their foreign outposts. A few small tubers can quickly turn into thousands of tons" (Rhoades, 2001, p. 140).

Since the potato was already rooted in British – and generally European – strategies signaling warnings against its cultivation was not appropriate when late blight's first appearance in Europe devastated the potato crops of Ireland in 1845 and 1846, bringing the infamous great Irish potato famine.

Queen Victoria proclaimed 24.3.1847 as a day of prayer and intercession. Salaman (1987, p. 314) excavates two noteworthy things from special prayers prepared for the occasion. Firstly, the extreme famine is tightly linked to “heavenly judgements [..] with which Almighty God is pleased to visit the iniquities of the land by a grievous scarcity and dearth of diverse articles of sustenance and necessaries of life.” Secondly, the word ’potato’ does not appear anywhere in prayers nor are the people of Ireland, who were notably potato dependent, given special attention, but the removal of the judgements is prayed for those ”who in many parts of the United Kingdom are suffering extreme famine and sickness.” The following 1847 potato crop in Ireland avoided blight, and the famine ended. Its bond to religion received further confirmation on this occasion. Generally, in European countries and their overseas colonies, the potato was food security, bringing health, population growth and urbanization (Nunn and Qian, 2011) which allowed many kinds of trades to prosper. Thus, blessing its cultivators and consumers, the potato established a strong connection to Christian religions. Traces of this connection may exist today although potato production is no longer dependent on European influence.

METHODS

Although much used in many fields of science – including marketing research and psychology which likewise study human behavior which inevitably influences commodity prices – the use of PC’s in purely economic contexts has been relatively rare. The idea that is popular and seen useful in other sciences, namely interpreting or identifying factors based on their loadings, is still largely strange to many economists. The basic reason is given by the unlikely success in interpretation, in Thomas (1997, p. 244) and Greene (1993, p. 273). We should expect that this approach, properly and carefully implemented, should bring discoveries also in the largely neglected domain of economics. For acquiring sensible economic interpretations for our exploration, we should firstly possess variables and data sample that are appropriate for the task. Such carefulness may considerably aid the interpretation of PC loadings. Secondly, economic theories, common sense, observational proofs and simplicity should drive the interpretations.

PRINCIPAL COMPONENT ANALYSIS AND REGRESSION

PC analysis converts a set of variables into a set of new variables which are linearly uncorrelated with each other. This set of new variables, PC’s, is generated as a linear combination of original variables so that the first one, PC1, takes the maximal variance of the data. PC2 has the largest possible variance and orthogonality to PC1. Similarly, each PC has maximal variance but is uncorrelated with preceding PC’s. Next we present statistical construction of PC’s for regression by orthogonal transformation of the eigenvectors that are received from the eigenvalue decomposition of explanatory data correlation matrix.

CONSTRUCTING PC'S AND REGRESSION FOR PRESENT ANALYSIS

Let X be the original data matrix, countries representing n=40 rows and social variables representing 33 columns. Let R be the correlation matrix of X. Its decomposition matrices, from $R = V\Lambda V^T$, then have dimensions 33x33. The diagonal matrix Λ contains the eigenvalues of R in the diagonal. Their corresponding eigenvectors are the columns *of* V. Eigenvalues are proportions of the total data variance, which their corresponding eigenvectors capture. Each column of V represents PC loadings of the original 33 variables. The standardized version of X is used to transform loadings-matrix V columns into orthogonal vectors. Every column in X has all its elements subtracted with the column mean and divided by the column standard deviation of X, giving matrix Z. Equation 1 then establishes PC matrix O (dimensions 40x33).

$$O = ZV \quad (1)$$

Each of the 33 columns of O represents scores of its corresponding PC for the 40 countries. For a constant to be included in estimation results to follow, the matrix O is added to a column of 1's. Let this 40x34 regression matrix be called Ω. Then we regress our 40x1 potato price vector y on the matrix Ω (or the K first columns), thus receiving a 34x1 coefficient vector θ for the unobserved error term ε, with $y = \Omega\theta+\varepsilon$. Minimizing e^Te, the sum of squared observed residuals, leads to OLS coefficient estimates of Equation 2.

$$\hat{\theta} = (\Omega^T\Omega)^{-1}\Omega^T y \quad (2)$$

For running PC regression with statistical software, see Everitt and Hothorn (2011, pp. 63-92). For OLS coefficient estimator properties, see Greene (1993, pp. 292-293).

RESULTS

IMPORTANCE OF THE COMPONENTS AND THE REGRESSION RESULTS

Table 2 presents the importance in terms of the variance that the seven first PC's hold of the 33 original data variables and their explanatory shares in the regression.

TABLE 2: IMPORTANCE AND EXPLANATORY POWER OF PC'S

PC	Proportion of Variance	Cumulative Prop.	R-squared	Cum. R-squared
PC1	0.268	0.268	0.000	0.000
PC2	0.123	0.392	0.068	0.068
PC3	0.084	0.475	0.117	0.185
PC4	0.077	0.553	0.000	0.185
PC5	0.075	0.627	0.002	0.187
PC6	0.067	0.694	0.197	0.384
PC7	0.054	0.748	0.121	0.505

OLS estimates are in table 3. The last PC that statistically significantly explains potato price is PC7.

TABLE 3: POTATO PRICE REGRESSION

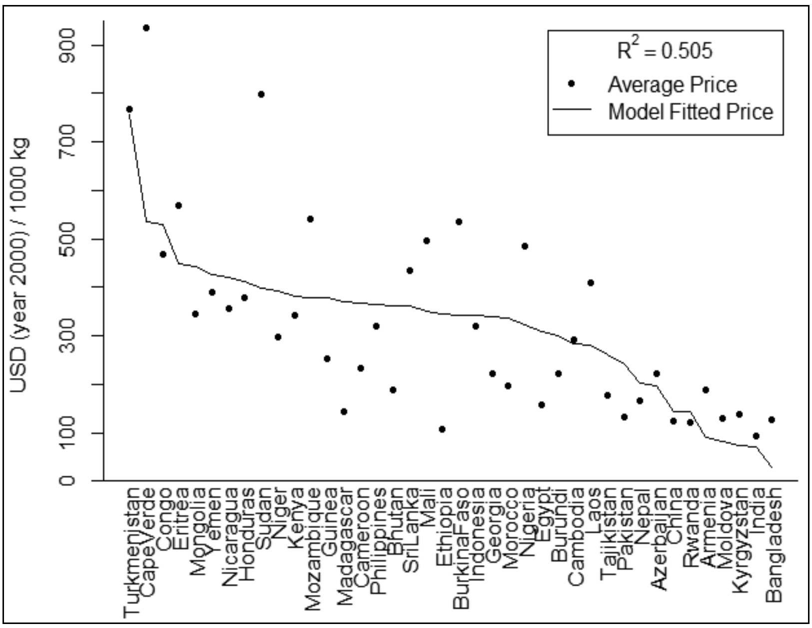
Endogenous: Potato Price, Exogenous: PC's 1-7 (scores)

	Estimate	T	P-value
(Constant)	320.25	12.94	0.000 *
PC1(Economic growth)	0.55	0.07	0.948
PC2(Agricultural poverty)	-25.99	-2.09	0.044 *
PC3(Knowledge)	-41.45	-2.75	0.010 *
PC4(Potato importance)	0.79	0.05	0.960
PC5(Market economy infrastructure)	-5.60	-0.35	0.728
PC6(Better business)	60.15	3.57	0.001 *
PC7(Potato suitability)	-52.62	-2.80	0.009 *

*Note: Statistically significant = *.*

Roughly half of the variation in potato price is explained by selected PC's (see figure 1).

FIGURE 1: POTATO PRICE BY COUNTRY:
AVERAGE REAL PRODUCER PRICES AND MODEL FIT



Countries that have their average potato price vertically closer to the model fitted price line are better conforming to the model explanation. Having now regressed potato price on PC's 1 to 7, we are ready to interpret factors affecting potato price.

PRINCIPAL COMPONENTS

We will next interpret and name PC's 1-7.

If the effect direction on potato price is negative for a PC, (-) is marked in the data table of that specific PC. Similarly (+) marks positive effect on potato price. The signs are taken directly from the table 3 regression coefficient estimates. We still need to decide the limit for meaningful loadings, usually an integer multiple of 0.10 that leaves some loadings for all important PC's. We therefore include only those loadings which satisfy

$$|loading| > 0.20.$$

Interpreting the most important PC's should interest us the most here. Equipped with the results of PC regression, especially the effect sign and significance on potato price, together with accepted PC loadings we are now ready for the task of interpretation of tables 4-10.

PC1: ECONOMIC GROWTH

TABLE 4: PC1: ECONOMIC GROWTH (+)

Original variable	Loading
PGrowthRate	-0.272
PerCapGDP	0.270
Hdi	0.304
LifeExp	0.255
PopUrbanShare	0.202
ChildM	-0.238
AgricultureGDP	-0.222
ImportVPerCapita	0.295
TotalAgriCapitalStockVPerAgriPopu	0.218
MeatProductionPerCapita	0.211

PC1 is not statistically significant in predicting potato producer price. Its loadings are characteristic of economic growth, a macroeconomic trend that has the foremost visibility as a candidate to help solve developing country problems. Higher incomes generally lead to rising potato demand in developing countries (Horton, 1987, p. 70) and thus higher potato prices can follow economic growth.

PC2: AGRICULTURAL POVERTY

The three uppermost loadings in table 5 are relating values of livestock, plantation crops and total agricultural capital stock, respectively, in the numerator to the number of workers in agriculture in the denominator. Their negativity signals that the number of workers in agriculture is high compared to the value of holdings.

TABLE 5: PC2: AGRICULTURAL POVERTY (-)

Original variable	Loading
LivestockValuePerAgriPop	-0.380
PlantationCropsVPerAgriPopulation	-0.361
TotalAgriCapitalStockVPerAgriPopu	-0.300
PasturesProportionToArableLand	-0.403
IrrigatedShareOfArableLand	0.237
MeatProductionPerCapita	-0.221

The three lowermost loadings indicate that arable land is largely irrigated for cultivation instead of using it as animal pastures, and low meat production per capita has ensued. These reasonably allow inferring also the typical land ownership structure; the best lands are concentrated into the hands of wealthier farmers, who employ masses of landless labor workers in their fields. Irrigation is usually used on larger farms, whereas poorer small-scale farmers would wish to diversify into owning some animals to cope with agricultural seasonality or as an insurance against poor crops (Antazena et al., 2005, p. 195).

Farmer poverty lowers potato producer prices, as poor farmers, lacking negotiating power and choices for other livelihoods such as meat production, are forced to accept the terms of trade of potato purchasers and sell their produce and labor cheaply. The effect of PC2 on potato price is negative and statistically significant. Agricultural poverty is related to supply constraints as poor potato cultivators often experience marketing constraints. Obviously, agricultural poverty leads to a high labor input in agriculture.

PC3: KNOWLEDGE

TABLE 6: PC3: KNOWLEDGE (-)

Original variable	Loading
Christian	0.440
WaterUseAg	-0.237
WaterUseIn	0.208
AgricultureExport	0.345
MaizePrice	-0.280
ExportVPerCapita	-0.247
PotProdPerCap	0.202
PotProdPerAgriPop	0.238
ArableLandShareOfLandArea	0.298
CerealProductionPerCapita	-0.249

PC3: Both potato production and consumption are high. Maize price is also low although cereal production is low. Low dependence on cereals indicates that there exists some technology or means for conserving perishable potatoes until a new potato crop

arrives, possibly even for export as indicated by the high share of low valued agricultural exports. Water may be used more for industries instead of agriculture as abundant arable land may benefit from European-like climate, disease environment and rainfall. Such circumstances were, according to Acemoglu et al. (2001), instrumental to mass migration from Europe. They are also benefiting the most from centuries of time-tested knowledge heritage that has accrued on European potato culture, seeds, field rotation, and other technology. The share of Christianity in earlier times often strongly correlated with potato cultivation as European values were transmitted or Europeans migrated in masses to colonies, bringing the potato with them.

The negative coefficient for PC3 is statistically significant. PC3=Knowledge is related to supply side constraints. Such constraints are missing potato technologies or lacking knowledge on proper cultivation practices.

PC4: POTATO IMPORTANCE

In PC-loadings, in table 7, producing maize is expensive and the share of permanent crops on arable land is low. In a sparsely populated country one likely reason is poor geography for cereal cultivation. Also, fish production is negligible. Still agriculture is badly needed as seen from its high share of GDP. Potato is bringing great harvests helped by appropriate agricultural machines and equipment.

TABLE 7: PC4: POTATO IMPORTANCE (+)

Original variable	Loading
PDensity	-0.217
Population	-0.276
AgricultureGDP	0.213
MaizePrice	0.246
PotProdPerCap	0.338
PotProdPerAgriPop	0.335
MachEquipVPerAgriPopulation	0.365
PermanentCropsShareOfArableLand	-0.232
FishProductionPerCapita	-0.438

PC4=Potato importance. We should note that higher potato importance means higher potato price. Although the coefficient is not statistically significant, its sign strengthens the validity of the model, since the existence of supply constraints logically means that production is usually lagging behind increasing demand. Fuglie (2007, p. 362-363) considers the issue of higher productivity leading to oversupply and lower market price, but opposing it notes that in most developing countries the potato is considered a high-value and high-profit crop with strong and elastic market demand.

PC5: MARKET ECONOMY INFRASTRUCTURE

High services share of GDP, high life expectancy and low child mortality, and also water use in agriculture instead of industries are clearly seen in PC5. Christian share is low and export value is low; there is no usual dependence on valuable exports of natural resources, common to developing countries with extractive colonial institution heritage. The incentives to land development are in place and agricultural imports are answering to remaining nutritional needs.

TABLE 8: PC5:
MARKET ECONOMY INFRASTRUCTURE (-)

Original variable	Loading
Christian	-0.202
ServGDP	0.265
LifeExp	0.245
ChildM	-0.260
WaterUseAg	0.423
WaterUseIn	-0.304
AgricultureImp	0.219
ExportVPerCapita	-0.373
IrrigatedShareOfArableLand	0.218

Improving infrastructures for the market economy is a macroeconomic trend in developing countries. Also, earlier centrally planned infrastructures are being upgraded to service market forces; implementing capitalist reforms, agriculture and trade liberalization, to thus meet challenges of increasing competition brought by globalization. The process has presented considerable difficulties for many countries. Nyairo (2011) notes that food security remains a challenge in many developing countries several decades after agricultural market and economic liberalization but countries with vibrant economic structures have come off better than countries with a firm socially founded system. A high value export sector, declining due to increasing competition, is a cause to eroding food import potential.

Although the negative coefficient is not statistically significant, we notice that more market-oriented infrastructures, better positioned for globalization, may produce food cheaper. PC5 is also related to potato supply constraints. Lacking market infrastructure is a marketing constraint also to potato supply, discouraging cultivation, thus indirectly reducing production and increasing price.

PC6: BETTER BUSINESS

TABLE 9: PC6: BETTER BUSINESS (+)

Original variable	Loading
Christian	0.260
PDensity	-0.333
Population	-0.294
PopUrbanShare	0.313
AgricultureImp	0.348
ArableLandShareOfLandArea	-0.395
CerealProductionPerCapita	-0.231

PC6 characteristics are relatively poor geography for cultivation through negative loadings on population density and arable land share of land area. Cereal production is low. Level of urbanization is high; the likely reasons are insecurity of the countryside, uncertainty in land ownership, extractive agricultural taxation or trade policies favoring food imports to own production. Extractive colonial institution inheritance can be inferred from a high Christian proportion and poor geography (Acemoglu et al., 2001).

Reasons for better business are explored in Books III and IV of the Wealth of Nations:

> *"What circumstances in the policy of Europe have given the trades which are carried on in towns so great an advantage over that which is carried on in the country that private persons frequently find it more for their advantage to employ their capitals in the most distant carrying trades of Asia and America than in the improvement and cultivation of the most fertile fields in their own neighborhood, I shall endeavor to explain at full length in the two following books" (Smith [1776] 1904, par. II.5.36).*

In summary, urbanization is maintained with imported food, since better alternative business opportunities discourage efforts to improve land for cultivation. Such production disincentives are a constraint to supply, and low production causes the potato producer price to remain high.

PC7: POTATO SUITABILITY

TABLE 10: PC7: POTATO SUITABILITY (-)

Original variable	Loading
ServGDP	-0.406
AgricultureExport	-0.225
AgricultureImp	0.215
MaizePrice	-0.471
PotProdPerCap	0.259
PotProdPerAgriPop	0.288
MachEquipVPerAgriPopulation	-0.298

Here potato production is high, without expensive machinery and equipment, although agricultural imports may cause discouragingly low substitute maize price.

Potato has therefore very suitable growing conditions. The share of agriculture of total exports is relatively small; potato rots easily. Services GDP share is small, implying that the remaining shares, agriculture and especially industry, have greater shares. The potato supplies calories for industrial expansion. (Nunn and Qian, 2011, pp. 605-607) develops a model to demonstrate how increased agricultural productivity, brought by the potato, increases jobs in manufacturing.

The coefficient is significant, showing negative impact on potato price. This is unsurprising due to high level of potato production. PC7 can be named potato suitability. It relates to potato supply constraints through soil and environmental constraints. These include unpredictable rainfall, viruses, pests and diseases, which make the potato naturally less suitable for the tropics in particular – unless considerable capital through irrigation, fungicides, pesticides, and good quality planting materials, such as potato seeds, is applied together with locally specialized technology and knowledge for their proper use.

SUMMARY DISCUSSIONS

LAND, LABOR, CAPITAL AND TECHNOLOGY

Exploring orthogonal maximal variance dimensions of our social data, we studied seven PC's. Four of them statistically significantly affect potato producer price. Table 11 summarizes these four explainers of potato price level with simple examples.

TABLE 11: SUMMARY OF PC'S THAT ARE MACROECONOMIC FACTORS OF PRODUCTION

PC	Simple Examples with Effect on Potato Producer Price, (-) or (+)
Better business	Capital into urban business advantageous over improving land (+)
Potato suitability	Land allocated since potato especially suitable for cultivation (-)
Knowledge	Technology on potato and knowledge of cultivation practices (-)
Agricultural poverty	Masses of cultivators having poor terms of trade at farm gates (-)

We have so far named these statistically significant PC's, based on their loadings, paying attention to their relation to potato supply constraints. Studying table 11 examples we notice they have another, more familiar, interpretation as macroeconomic or nation level factors of production. Better business PC6 measures the tendency of capital inflow into urban business instead of rural agriculture. Its inverse is therefore a measure for Capital input. Potato suitability PC7 is a measure for Land input. Knowledge PC3 is a measure for Technology input. Agricultural poverty PC2 is a measure for Labor input since masses of agricultural laborers are available for near subsistence pay for their work or produce. Increase in each of these four inputs – land, labor, capital and technology – allows increasing production. These added positive inputs have naturally an opposite effect on potato producer price due to increasing potato supply.

Consider a standard agricultural production function *f*, presented in unspecified functional form, *Production* = *f*(*Land, Labor, Capital, Technology*). Supply and demand curves cross each other at the market equilibrium price. Increasing production by added inputs will shift the supply curve, and a lower price will be achieved at a new equilibrium position with the demand curve. Easing of constraints to supply, i.e. production, is likely affecting producer price with greater determinacy than demand shifts. The function *g* of price, $Price = g(Land, Labor, Capital, Technology) = \theta_0 + \theta_1 Land + \theta_2 Labor + \theta_3 Capital + \theta_4 Technology$, then can explain half of cross-border price variation with statistically significant PC's as estimated in this study.

MACROECONOMIC TRENDS

Three PC's do not attain statistical significance in explaining potato price. Table 12 lists these ongoing trends with simple examples and their effects on potato producer price.

TABLE 12: SUMMARY OF PC'S THAT ARE MACROECONOMIC TRENDS

PC	Simple Examples with Effect on Potato Price, (-) or (+)
Economic growth	Buying power brings increasing potato demand (+)
Potato importance	Increasing demand surpasses also growing supply (+)
Market economy infrastructure	Efficiency of markets lowers production costs (-)

We noticed on the first of the macroeconomic trends, PC1=Economic growth, that its effect on potato producer price is positive. Rising potato demand in developing countries is expected as a reaction to economic growth (Horton, 1987, p. 70). Added incomes can lead people in developing countries to diversify their consumption habits, thus increasing potato demand and use, and price.

On the second of the macroeconomic trends, PC4=Potato importance, we noticed that increasing potato use accompanies increasing price. This is in line with the theory of supply constraints of the introductory section. It is mainly supply that limits potato use, not demand. When potato importance grows, increases in supply due to successful removal of its constraints may unleash even greater potato demand (Fuglie, 2007, p. 362-363). Our results confirm that the removal of supply constraints in developing countries may result in producer price increase as it allows growing importance of the potato.

The third macroeconomic trend, PC5, is affecting improvements to market economy infrastructures. In addition to allowing greater market access on the demand side, this trend can naturally aid potato producers also in supply constraints they are facing.

CONCLUDING NOTES

The classic factor inputs are in routine use in economics. We encountered them through reconsidering table 11 examples of our dimension reduction interpretations. As general policy recommendation, allocation strategies for public and private potato advancement campaigns can be evaluated for long run durability by considering how they address primary reasons for restricted national input use in corresponding PC's.

Capitalizing poor potato growers, helping them to improve their equipment though farm credit or low-priced access to fertilizers, pesticides, good quality planting material and seed, would seem a natural solution. Such may also bring promising short run results in potato productivity and lower prices. For understanding how sustainable benefits could remain in developing country conditions, we need a more sophisticated view through examining how the capital input accrues through the typical data pattern of developing countries, presented by the loadings of Better business PC6. We notice that the path leading to low capital input in developing countries is primarily due to better business alternatives and capital finding its way to business in cities rather than into the countryside. Obviously, if such business atmosphere is not improved, any added capital inputs to potato cultivation are in danger of being only temporary. Even the farmer is tempted to sell the inputs and have proceeds directed to some urban business opportunity that is less vulnerable to theft, spoilage, price risk, taxation or land extraction. Due to these reasons, acquiring national policy changes is often needed as well in order to reap lasting benefits from addressing growers' capital and also technology input related supply constraints.

The potato certainly has potential to change economies in developing countries; (Zhang and Hu, 2014) guides through an example how Anding county, with a harsh natural environment, was turned into "potato capital of China". Although both the demand and supply side needed solutions, we should notice that the local government worked first to ease potato supply side constraints through concentrated efforts to improve factor inputs of table 11. Based on experiments on technology of terrace fields, land allocation increased on hillsides, which earlier had not held rainfall. This was initially accomplished by labor allocation and later by capital allocation and machinery. Only after supply easing had been effective and the potato had received a recognized status, demand side importance increased alongside, and its constraints needed solutions such as improving rail access to farther market areas.

Empowering poor cultivators and consumers with the potato works directly to their benefit, which is wise, remembering social dangers of neglecting food security. Economic growth in itself is often affecting increases in potato price, which may lead poorer people farther from potato use. Infrastructures targeted particularly for the potato are a key ingredient to its greater importance, making increased inputs to potato cultivation more attractive. Public roads to production areas, communication channels, cold storage and electricity availability lower price volatility and risks to potato merchants, thereby leading to lower marketing margins, giving greater share to the poor producers, while also increasing affordable potato supply for the urban poor.

ENDNOTE

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ARTICLE III

O. Salmensuu, “A potato market integration analysis for India: Speculation in Delhi slows price integration,” *Review of Market Integration* **9**, 111–138 (2017).

Article

A Potato Market Integration Analysis for India: Speculation in Delhi Slows Price Integration

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Olli Salmensuu[1]

Abstract

We constructed co-integration relation and Engle–Granger type error-correction models for the wholesale potato markets of three Indian regions. In addition to the standard result of the existence of error-correction mechanisms in Indian potato markets, the chosen setting allows for inspection of how these market areas differ in their return to the co-integrating relation. The northern area differed from the other market relations studied with its slower return to equilibrium, 8.0–8.6 weeks compared to 5.0–6.3 weeks. The result may indicate that the Delhi and Agra markets are central playing grounds for speculators, speculators manipulating potato prices farther and longer time away from the natural price relation. Short-run or same-week elasticities between the markets studied ranged from 0.12 to 0.34. Long-run elasticities ranged from 0.55 to 1.11. Short-run effect has to be multiplied by approximately four to obtain the long-run effect.

Keywords

Market integration, co-integration, error-correction, speculation, developing countries

JEL: Q13, Q18, R12, R32

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Introduction

Our choice of studying intra-country wholesale potato prices in India is an attempt to gain insights into potato market integration in a developing country that has striven to unleash potential of the potato. Past decades especially have seen advances in subtropical climate cultivation and cold storage capacity. Although its importance has been growing, potato is not a staple food in India; it is considered a complementary vegetable. One important factor that deters wider potato use in India, and in developing countries more generally, is its price fluctuation. The policies that target the most needy in developing countries would benefit from knowledge of the root causes of such deterrents.

Price differentials between different areas tend to get reduced as private traders move food from low-price to high-price areas arbitraging on the price differential. Certain exceptions to this process may even increase the differential. If the low-price area is deprived of purchasing power, income or assets, the price differential may get even larger, with food escaping to richer areas. Also, the price differential between areas should exceed transport costs. Credit constraints, poor information or insufficient communications may also block the process. Collusion among traders is another exception to the process. Inter-temporal price speculation is also a complicating factor (Drèze & Sen, 1989, pp. 89–95).

Error-correction method price analysis is widely practised in econometrics. Following Engle and Granger (1987), time series of the same order of integration set into a co-integrating regression equation with a stationary error can be used to build an error-correction model. In related literature, Ó Gráda (2001, 2005), error-correction model approach was used to test whether and when famines changed the price adjustment process between markets in European history. Cumbersome controls to inter-regional trade were not unknown in historical Europe, a similarity to contemporary India. The method used was Engle–Granger as in current study. Potato price co-integration, both retail and wholesale, in markets of India, has been studied (Basu & Dinda [2003] and Basu [2006, 2010] concentrate on West Bengal), but often with Johansen method instead. In its general setting, Johansen method allows more than two markets in the same equation and removes the need to determine the central area to which other prices are adjusting, but loses the possibility of incorporating current period influence. We will solve the centrality problem by using arrival quantities in judging the main market.

Likewise, as in aforementioned studies, we find evidence of market integration. It will be established that Delhi and Agra have slower return to equilibrium with Shimla than other markets indicating that, although they are not central production-wise, they may be central markets for price speculation. An example of a somewhat less developed road and information network and its corresponding market integration study is seen in Jaleta and Gebremedhin (2012) concerning teff and wheat prices in Ethiopia. The conclusion is that such infrastructures are crucial to obtain greater market integration. This is another indication that underlines the unexpectedness of the result concerning central Delhi area, which food price speculation would explain. The post-hoc inference on results of the current study on inter-regional price and market integration are based on existence of inter-temporal speculation. The idea is that speculation may be more prevalent in Delhi and Agra than in the other markets studied, as indicated by their slower return to natural market integration price relation. This happens despite their central location, which might reduce any inter-regional exceptions to price differential elimination. Inter-temporal speculators in Delhi and Agra may cause the price to persist, and thereby not adjust so easily to the natural price relation with other Indian potato markets.

Data

We had data available from Indian National Horticulture Board (NHB) for 33 different wholesale potato marketplaces from 2002 until 2009. The price data was available in daily, weekly and monthly formats.

The markets for this study were selected based on year-round importance, measured by number of weeks with NHB price quotation during the whole data period. The seven wholesale centres chosen had each less than 10 weekly observations missing for the whole data period. Thus, they were year-round important trading centres already in the beginning of the data period and remained so to its end.

As an alternative, we also considered daily time series which would have given one desirable thing, the highest possible frequency of data for our study. On the other hand, for weekly data, a practical deflator was available, Indian weekly published wholesale price index. Also, NHB daily data contained more breaks without price information.

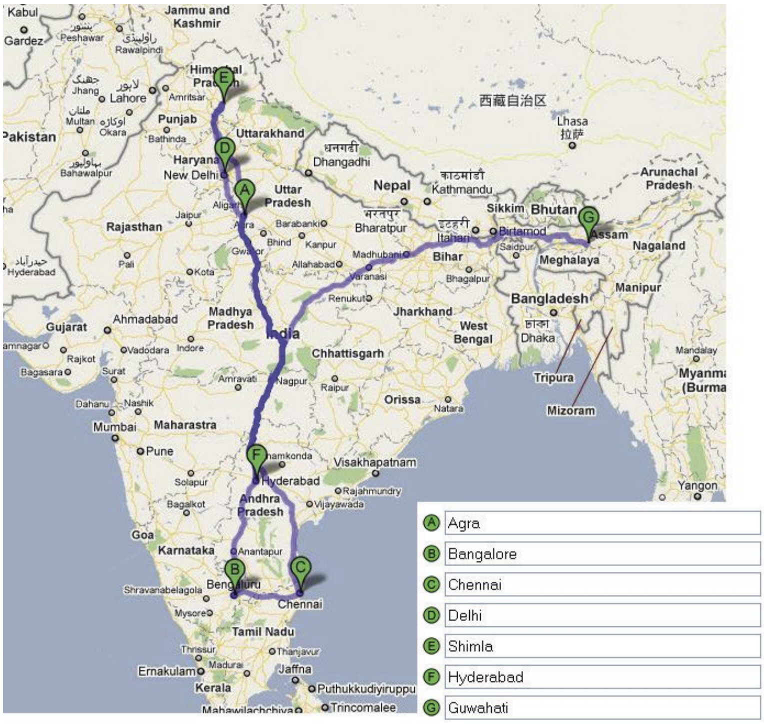

Figure 1. Map of India and Chosen Markets

Source: Map data ©2010 Google, Google (fair use).

This qualification for year-round weekly importance gives us an interesting starting point for the study. We have three northern Indian cities, Delhi, Agra and Shimla, three southern Indian cities, Bangalore, Chennai and Hyderabad, and, lastly, Guwahati which is located farther in the east. These are seen in the Google map of Figure 1. Except for Agra, the cold-storage hub of India, all these were the largest cities in their states and, with the exception of Guwahati, also state capital cities.

Comparisons of the potato prices in northern area, southern area and in between the three areas are presented in Figures 2, 3 and 4, respectively. Potato prices are deflated for the purposes of econometric study by the Indian wholesale price index to acquire real prices. Then further, natural logarithms of real potato prices are taken. This results in the series of our study that are presented in Figure 5.

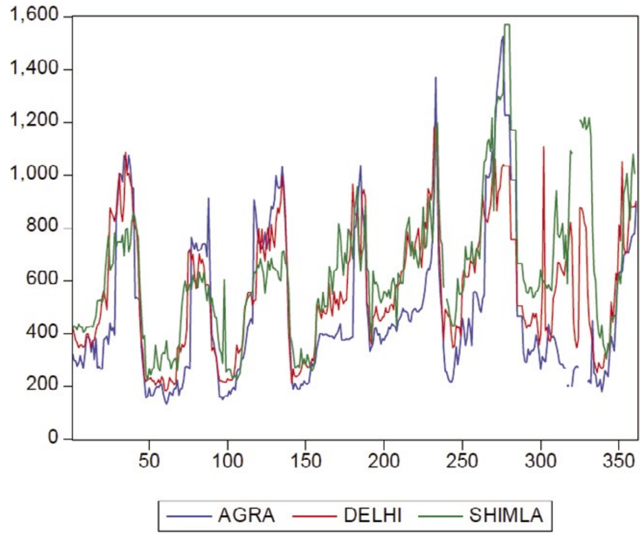

Figure 2. Northern Markets' Prices Compared with Each Other. Weekly Count from 2002 to 2009 Is in the x-axis. Potato Price in Rupees Per 100 kg Is in the y-axis

Source: Drawn by the author using Eviews software.

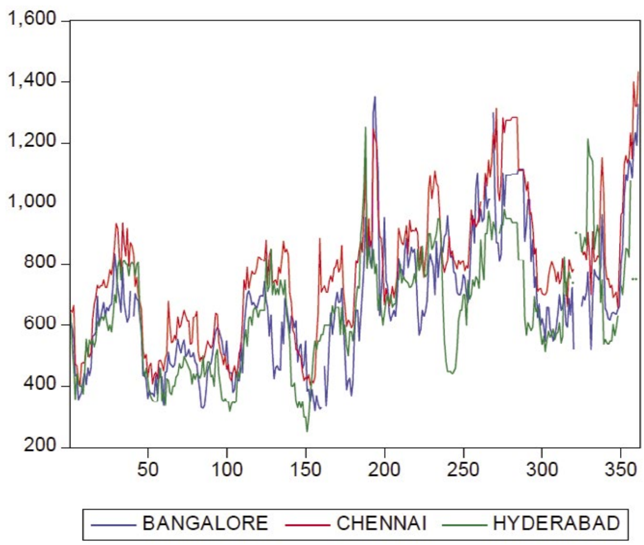

Figure 3. Southern Markets' Prices Compared with Each Other

Source: Drawn by the author using Eviews software.

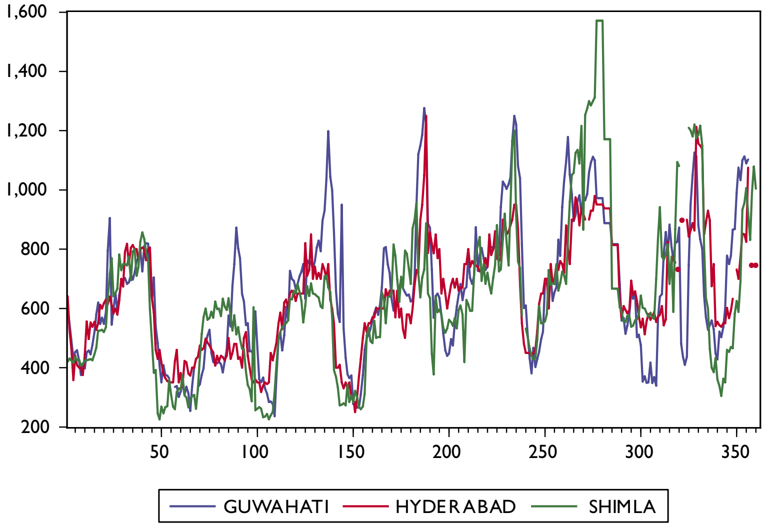

Figure 4. Northern, Southern and Eastern Markets Compared to Each Other

Source: Drawn by the author using Eviews software.

Methods

Testing the Order of Integration

Error-correction approach demands that all series are of same order of integration. KPSS testing fails to reject the stationary null hypothesis for each of the series at 5 per cent risk level. We conclude that all seven potato price series are of the same order of integration. Since the series are I(0), we will also be able to compare elasticities to those estimated by ARDL(1,1) models.

Arrival Quantities Determine Adjustment Direction

Johansen is another much used method, but we can, in this case, use the Engle–Granger method by defining the adjustment directions. It allows us to take into account same period change in the explanatory variable.

Average weekly arrival quantities to marketplaces help set up the starting point for our analysis. We assume that regionally bigger wholesale centres have local influence on smaller markets, that is, a smaller centre

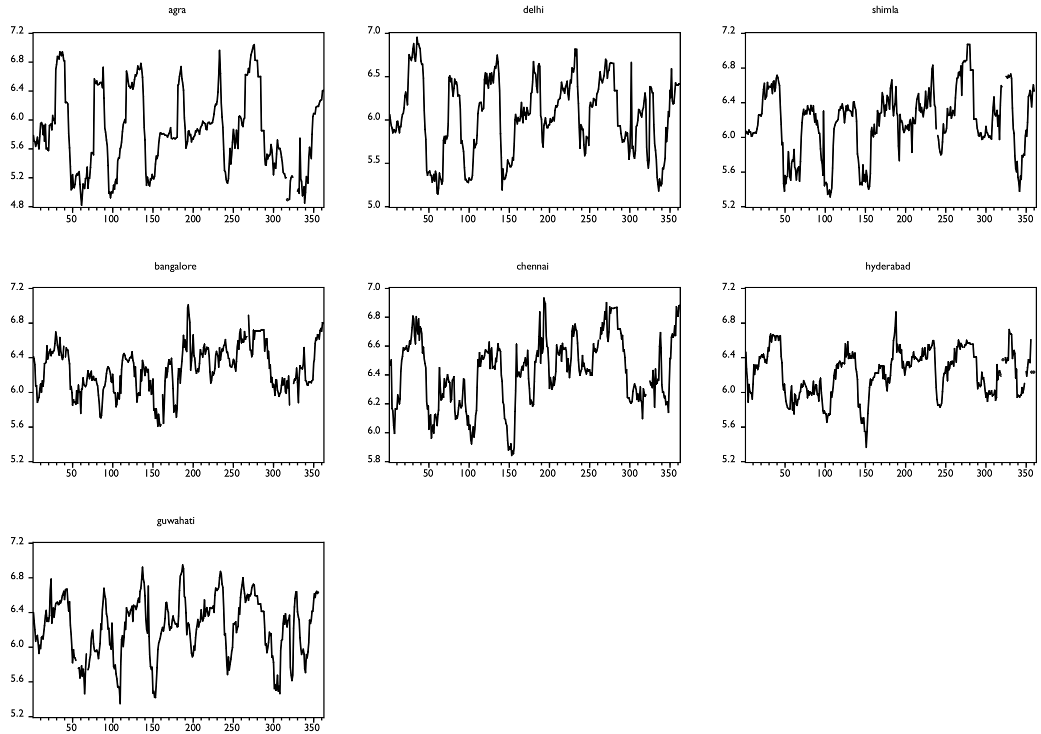

Figure 5. Price Series of Our Study: Log Real Prices

Source: Drawn by the author using Eviews software.

adjusts its price level towards the equilibrium to correct the difference to the bigger trading centre. Smaller markets easily have their price level changed, by less change in arrival quantity, compared to larger markets, regardless of whether this change in potato flow is negative or positive, or due to—as often is—other regions rather than the larger market nearby.

We set the bigger wholesale marketplaces as inter-regional linkages. For their inter-regional influence direction, we weigh the regional production and its phase. The northern region states account for a great share in Indian production, with inter-state potato flow southward. Eastern region Assam hills harvesting in January–February is preceded by southern region harvesting in the plains of Karnataka during October–December and also by harvests in the plains of Uttar Pradesh starting in December.

Thus, we have that in northern sector, prices in Agra and Delhi are explained by prices in Shimla. And prices in Bangalore and Chennai are explained by Hyderabad prices in the southern sector. For inter-sector effects, prices of the eastern sector and Guwahati are explained by prices in Shimla and then Hyderabad. Hyderabad prices are explained by prices in Shimla. This gives us seven equations to model with directions of influence shown by arrows in Figure 6.

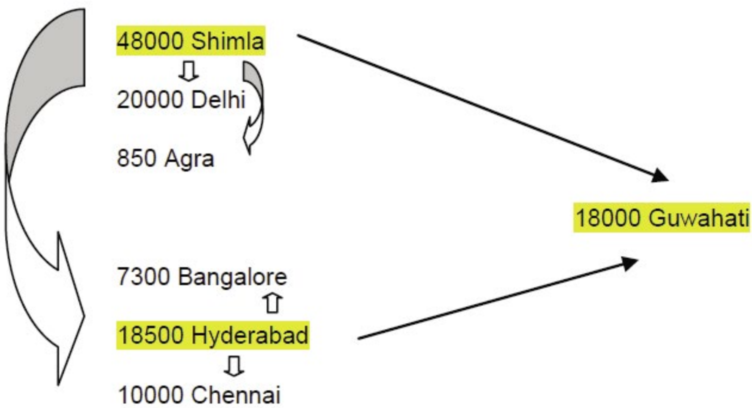

Figure 6. Adjusting is Taking Effect Following the Direction of the Arrows. Quantities are Average Weekly Arrival Quantities Measured in Tons. Intra-regionally Larger (marked in yellow) Wholesale Markets Locally Influence the Price Level in Smaller Ones and are Influenced by each Other by their Produce Inter-regionally. The Largest Arrow Depicts the Trend of Inter-state Potato Flow from Northern Region Southward. Black Arrows Indicate Eastern Region Adjustments by the Two

Source: Drawn by the author.

Models

First, we estimate the co-integration relation equations. For them, our models follow Equation (1):

$$y_t = \theta_0 + \theta_1 x_t + e_t. \tag{1}$$

And error-correction models are then of the format of Equation (2):

$$dy_t = \beta_0 + \beta_1 dx_t + \beta_2 e_{t-1} + u_t. \tag{2}$$

And ARDL(1,1) models are then of the format of Equation (3):

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \gamma_0 x_t + \gamma_1 x_{t-1} + \varepsilon_t. \tag{3}$$

Results

The residual of co-integration equation is stationary as it is a linear combination of two stationary processes. We can then conclude that there exists a co-integration relation in all cases between the series under study. Stability test graphs of the error-correction equations show decent stability of the equation parameters, meaning that no structural change, which would affect error-correction modelling, is happening during the period of study which saw the start of futures trading in potato, and worldwide food crisis. Error-correction model equation residual correlograms and recursive residuals are found in the Appendix Figures A1–A7. Error-correction model equation recursive coefficients are presented in Appendix Figures B1–B7. We now move to study the seven markets' co-integration equations and error-correction equations and their numerical implications more closely. ARDL(1,1) models are used for verification. All results are in line with ARDL(1,1) results. We have used White's heteroscedasticity consistent standard errors (in parenthesis below coefficient estimates) to account for heteroscedasticity.

Agra–Shimla Modelling

Co-integration Equation

$$Agra_t = -1.02 + 1.11 Shimla_t + e_t$$

$$(0.30) \quad (0.05) \qquad R^2 = 0.56 \qquad N = 348$$

In the long run, 1 per cent change in Shimla price entails 1.11 per cent change in Agra price. This is comparable to ARDL(1,1)-model calculated elasticity of 1.10.

Error-correction Model

$$d(Agra)_t = 0.00 + 0.32d(Shimla)_t - 0.12e_{t-1} + u_t$$
$$(0.01)\ (0.08) \qquad (0.04) \quad R^2 = 0.10 \quad N = 343$$

1 per cent change in Shimla price entails 0.32 per cent same-week change in Agra price. This is comparable to ARDL(1,1)-model short-run or same-week elasticity of 0.32. Error-correcting term is 0.125, so every week brings 12.5 per cent return from the disequilibrium level towards the co-integration equation long-run equilibrium level. Equilibrium level is, thus, reached again 1/0.125 = 8.0 weeks after the shock.

ARDL(1,1) Model

$$Agra_t = -0.11 + 0.88Agra_{t-1} + 0.32Shimla_t - 0.18Shimla_{t-1} + \varepsilon_t$$
$$(0.16)\ (0.04) \qquad (0.08) \qquad (0.09) \quad R^2 = 0.91 \quad N = 343$$

Long-run elasticity is calculated $(\gamma_0 + \gamma_1)/(1 - \alpha_1)$, thus we received $(0.32 - 0.185)/(1 - 0.88) = 1.10$.

Delhi–Shimla Modelling

Co-integration Equation

$$Delhi_t = 0.10 + 0.96Shimla_t + e_t$$
$$(0.21)\ (0.03) \quad R^2 = 0.69 \quad N = 355$$

In the long run, 1 per cent change in Shimla price entails 0.96 per cent change in Delhi price. This is comparable to ARDL(1,1)-model calculated elasticity of 0.62.

Error-correction Model

$$d(Delhi)_t = -0.00 + 0.34d(Shimla)_t - 0.12e_{t-1} + u_t$$
$$(0.01)\ (0.08) \qquad (0.05) \quad R^2 = 0.10 \quad N = 352$$

1 per cent change in Shimla price entails 0.34 per cent same-week change in Delhi price. This is comparable to ARDL(1,1)-model short-run or same-week elasticity of 0.32. Error-correcting term is 0.116, so every week brings 11.6 per cent return from the disequilibrium level towards the co-integration equation long-run equilibrium level. Equilibrium level is, thus, reached again 1/0.116 = 8.6 weeks after the shock.

ARDL(1,1) Model

$$Delhi_t = 0.25 + 0.89 Delhi_{t-1} + 0.32 Shimla_t - 0.25 Shimla_{t-1} + \varepsilon_t$$
$$(0.11)\ (0.05) \qquad (0.08) \qquad (0.07) \quad R^2 = 0.90 \quad N = 352$$

Long-run elasticity is calculated (0.32−0.25)/(1−0.89) = 0.62.

Bangalore–Hyderabad Modelling

Co-integration Equation

$$Bangalore_t = 2.60 + 0.59 Hyderabad_t + e_t$$
$$(0.26)\ (0.04) \qquad R^2 = 0.34 \quad N = 348$$

In the long run, 1 per cent change in Hyderabad price entails 0.59 per cent change in Bangalore price. This is comparable to ARDL(1,1)-model calculated elasticity of 0.80.

Error-correction Model

$$d(Bangalore)_t = -0.00 + 0.22 d(Hyderabad)_t - 0.16 e_{t-1} + u_t$$
$$(0.01)\ (0.06) \qquad (0.04) \quad R^2 = 0.12 \quad N = 338$$

1 per cent change in Hyderabad price entails 0.22 per cent same-week change in Bangalore price. This is comparable to ARDL(1,1)-model short-run or same-week elasticity of 0.23. Error-correcting term is 0.159, so every week brings 15.9 per cent return from the disequilibrium level towards the co-integration equation long-run equilibrium level. Equilibrium level is, thus, reached again 1/0.159 = 6.3 weeks after the shock.

ARDL(1,1) Model

$$Bangalore_t = 0.21 + 0.84 Bangalore_{t-1} + 0.23\ Hyderabad_t - 0.11 Hyderabad_{t-1} + \varepsilon_t$$

(0.17) (0.04) (0.06) (0.06) $R^2 = 0.83$ $N = 338$

Long-run elasticity is calculated (0.23−0.11)/(1−0.84) = 0.80.

Chennai–Hyderabad Modelling

Co-integration Equation

$$Chennai_t = 2.06 + 0.70 Hyderabad_t + e_t$$

(0.18) (0.03) $R^2 = 0.62$ $N = 350$

In the long run, 1 per cent change in Hyderabad price entails 0.70 per cent change in Chennai price. This is comparable to ARDL(1,1)-model calculated elasticity of 0.81.

Error-correction Model

$$d(Chennai)_t = -0.00 + 0.30 d(Hyderabad)_t - 0.20 \mathrm{e}_{t-1} + u_t$$

(0.00) (0.06) (0.04) $R^2 = 0.19$ $N = 342$

1 per cent change in Hyderabad price entails 0.30 per cent same-week change in Chennai price. This is comparable to ARDL(1,1)-model short-run or same-week elasticity of 0.31. Error-correcting term is 0.195, so every week brings 19.5 per cent return from the disequilibrium level towards the co-integration equation long-run equilibrium level. Equilibrium level is, thus, reached again 1/0.195 = 5.1 weeks after the shock.

ARDL(1,1) Model

$$Chennai_t = 0.27 + 0.80 Chennai_{t-1} + 0.31 Hyderabad_t - 0.15\ Hyderabad_{t-1} + \varepsilon_t$$

(0.11) (0.04) (0.06) (0.07) $R^2 = 0.88$ $N = 342$

Long-run elasticity is calculated (0.31–0.15)/(1–0.80) = 0.81.

Guwahati–Shimla Modelling

Co-integration Equation

$$Guwahati_t = 2.30 + 0.64Shimla_t + e_t$$
$$(0.21)\ (0.03) \quad R^2 = 0.50 \quad N = 348$$

In the long run, 1 per cent change in Shimla price entails 0.64 per cent change in Guwahati price. This is comparable to ARDL(1,1)-model calculated elasticity of 0.81.

Error-correction Model

$$d(Guwahati)_t = 0.00 + 0.14d(Shimla)_t - 0.17e_{t-1} + u_t$$
$$(0.01)\ (0.06) \qquad (0.04) \quad R^2 = 0.13 \quad N = 343$$

1 per cent change in Shimla price entails 0.14 per cent same-week change in Guwahati price. This is comparable to ARDL(1,1)-model short-run or same-week elasticity of 0.16. Error-correcting term is 0.171, so every week brings 17.1 per cent return from the disequilibrium level towards the co-integration equation long-run equilibrium level. Equilibrium level is, thus, reached again 1/0.171 = 5.8 weeks after the shock.

ARDL(1,1) Model

$$Guwahati_t = 0.22 + 0.83Guwahati_{t-1} + 0.16Shimla_t$$
$$(0.14)\ (0.04) \qquad (0.06)$$
$$- 0.02\ Shimla_{t-1} + \varepsilon_t$$
$$(0.06) \quad R^2 = 0.88 \quad N = 343$$

Long-run elasticity is calculated (0.16–0.02)/(1–0.83) = 0.81.

Guwahati–Hyderabad Modelling

Co-integration Equation

$$Guwahati_t = 0.33 + 0.95Hyderabad_t + e_t$$
$$(0.30)\ (0.05) \quad R^2 = 0.55 \quad N = 348$$

In the long run, 1 per cent change in Hyderabad price entails 0.95 per cent change in Guwahati price. This is comparable to ARDL(1,1)-model calculated elasticity of 1.09.

Error-correction Model

$$d(Guwahati)_t = \underset{(0.01)}{0.00} + \underset{(0.07)}{0.34}d(Hyderabad)_t - \underset{(0.04)}{0.20}e_{t-1} + u_t \quad R^2 = 0.18 \quad N = 340$$

1 per cent change in Hyderabad price entails 0.34 per cent same-week change in Guwahati price. This is comparable to ARDL(1,1)-model short-run or same-week elasticity of 0.35. Error-correcting term is 0.201, so every week brings 20.1 per cent return from the disequilibrium level towards the co-integration equation long-run equilibrium level. Equilibrium level is, thus, reached again 1/0.201 = 5.0 weeks after the shock.

ARDL(1,1) Model

$$Guwahati_t = \underset{(0.18)}{-0.11} + \underset{(0.04)}{0.80}Guwahati_{t-1} + \underset{(0.07)}{0.35}Hyderabad_t - \underset{(0.07)}{0.13}Hyderabad_{t-1} + \varepsilon_t \quad R^2 = 0.87 \quad N = 340$$

Long-run elasticity is calculated (0.35−0.13)/(1−0.80) = 1.09.

Hyderabad–Shimla Modelling

Co-integration Equation

$$Hyderabad_t = \underset{(0.14)}{2.85} + \underset{(0.02)}{0.55}Shimla_t + e_t \quad R^2 = 0.59 \quad N = 350$$

In the long run, 1 per cent change in Shimla price entails 0.55 per cent change in Hyderabad price. This is comparable to ARDL(1,1)-model calculated elasticity of 0.61.

Error-correction Model

$$d(Hyderabad)_t = \underset{(0.01)}{0.00} + \underset{(0.04)}{0.12}d(Shimla)_t - \underset{(0.04)}{0.20}e_{t-1} + u_t \quad R^2 = 0.12 \quad N = 342$$

1 per cent change in Shimla price entails 0.12 per cent same-week change in Hyderabad price. This is comparable to ARDL(1,1)-model short-run or same-week elasticity of 0.13. Error-correcting term is 0.202, so every week brings 20.2 per cent return from the disequilibrium level towards the co-integration equation long-run equilibrium level. Equilibrium level is, thus, reached again 1/0.202 = 5.0 weeks after the shock.

ARDL(1,1) Model

$$Hyderabad_t = \underset{(0.14)}{0.50} + \underset{(0.03)}{0.80} Hyderabad_{t-1} + \underset{(0.05)}{0.13} Shimla_t$$

$$\underset{(0.04)}{-\,0.01}\; Shimla_{t-1} + \varepsilon_t \qquad R^2 = 0.87 \quad N = 342$$

Long-run elasticity is calculated (0.13–0.01)/(1–0.80) = 0.61.

Summary Discussion

Same-week elasticities vary from 0.12 to 0.34, depending on the markets chosen. Long-run elasticities vary from 0.55 to 1.11, depending on the markets chosen. So, the short-run or same-week effect is multiplied by 3.26–4.58 with a mean of approximately 3.9 to get a long-run elasticity.

Inter-area-effects: 5.0–5.8 weeks return to equilibrium

Intra-area-effects:

North: 8.0–8.6 weeks return to equilibrium

South: 5.1–6.3 weeks return to equilibrium

Strikingly, the two first models for northern area are separated from other models by their markedly slower return to equilibrium price relation. Delhi and Agra's return to equilibrium relation with respect to Shimla is slower than the restoration of equilibrium in farther located markets—Hyderabad in the south and Guwahati in the east—with respect to Shimla. It is not easy to come up with a clear explanation for this through inter-regional exceptions discussed in Section 1.

On the contrary, it would be expected that arbitraging price differentials would be most effective near the capital city. What remains is the inter-temporal price speculation that could explain the results. It, therefore, seems that Delhi and Agra are the favourite playing grounds for speculators, and potato price there follows more stubbornly the anticipations of the speculators than the fundamentals of market pricing and integration with the rest of India.

Northern area models possess only a relatively high same-week elasticity estimated coefficient ranging from 0.32 to 0.34. Their long-run elasticity is also at a high range, close to unity, indicating a similar growth rate. But even such a linkage between northern area long-run prices and relatively high same-week responsiveness is not giving enough explanation for their separation from others through inter-regional statistical observations of this study. Long-run elasticity is close to unity, also in the Hyberabad–Shimla inter-area model. Chennai–Hyderabad intra-area model and Guwahati–Hyderabad inter-area model also have same-week elasticities close to that of northern area models.

To conclude, by studying inter-regional market dynamics in potato, we have found that there exists a good case for inter-temporal food price speculation in the capital city area. This is signalled by its comparably slower return to equilibrium price relation against the odds that would normally work to other direction, as presented in the Introduction.

Appendix A. Residual Correlogram and Recursive Residuals

Residual correlogram and graph of recursive residuals are presented Figures A1–A7 for Equation 2 residual u_t.

Sample: 2 360
Included observations: 343

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.041	0.041	0.5892	0.443
		2	0.070	0.068	2.2890	0.318
		3	0.060	0.055	3.5485	0.315
		4	0.151	0.143	11.487	0.022
		5	0.056	0.040	12.578	0.028
		6	-0.043	-0.069	13.230	0.040
		7	-0.007	-0.027	13.245	0.066
		8	-0.014	-0.035	13.319	0.101
		9	0.003	-0.002	13.322	0.149
		10	-0.093	-0.077	16.402	0.089
		11	0.067	0.088	17.997	0.082
		12	-0.167	-0.162	27.981	0.006

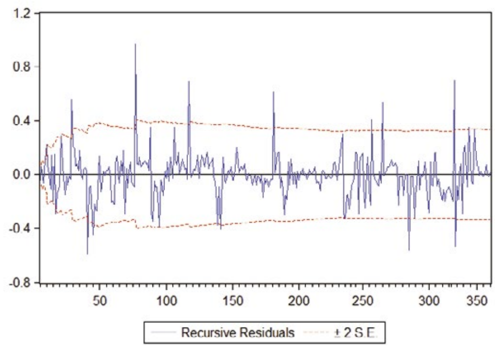

Figure A1. Agra–Shimla ECM

Sample: 2 360
Included observations: 352

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.068	0.068	1.6584	0.198
		2	0.027	0.022	1.9123	0.384
		3	-0.024	-0.027	2.1144	0.549
		4	0.069	0.072	3.8195	0.431
		5	0.031	0.023	4.1619	0.526
		6	0.094	0.087	7.3349	0.291
		7	0.106	0.098	11.379	0.123
		8	-0.029	-0.050	11.683	0.166
		9	-0.038	-0.036	12.201	0.202
		10	-0.008	-0.009	12.225	0.270
		11	-0.052	-0.073	13.228	0.279
		12	-0.057	-0.060	14.407	0.275

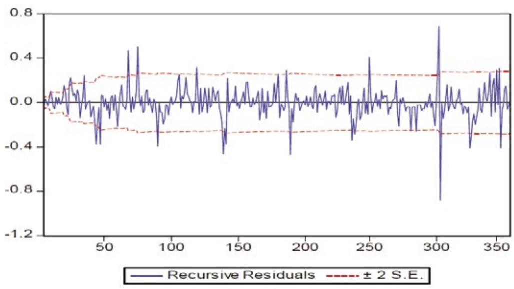

Figure A2. Delhi–Shimla ECM

Sample: 2 356
Included observations: 338

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.030	-0.030	0.3156	0.574
		2	0.034	0.033	0.7009	0.704
		3	0.006	0.008	0.7153	0.870
		4	0.053	0.052	1.6714	0.796
		5	0.000	0.003	1.6714	0.892
		6	0.061	0.058	2.9462	0.816
		7	-0.037	-0.035	3.4176	0.844
		8	-0.039	-0.048	3.9486	0.862
		9	-0.020	-0.022	4.0932	0.905
		10	-0.083	-0.088	6.4942	0.772
		11	-0.031	-0.031	6.8292	0.813
		12	0.021	0.026	6.9872	0.858

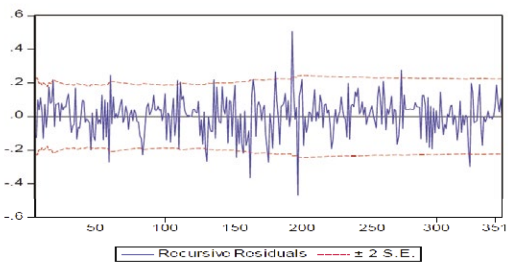

Figure A3. Bangalore–Hyderabad ECM

Sample: 2 356
Included observations: 342

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.031	-0.031	0.3316	0.565
		2	0.078	0.077	2.4173	0.299
		3	0.035	0.040	2.8361	0.418
		4	-0.101	-0.105	6.3658	0.173
		5	0.067	0.056	7.9310	0.160
		6	0.025	0.045	8.1530	0.227
		7	-0.031	-0.033	8.4836	0.292
		8	-0.044	-0.068	9.1759	0.328
		9	0.026	0.041	9.4110	0.400
		10	-0.092	-0.078	12.431	0.257
		11	0.050	0.034	13.336	0.272
		12	0.121	0.133	18.563	0.100

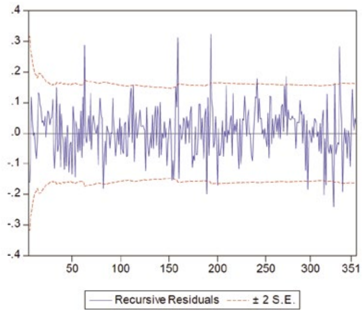

Figure A4. Chennai–Hyderabad ECM

Sample: 2 356
Included observations: 343

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.070	0.070	1.6955	0.193
		2	0.087	0.082	4.3045	0.116
		3	0.077	0.066	6.3498	0.096
		4	0.069	0.054	8.0281	0.091
		5	0.042	0.023	8.6387	0.124
		6	-0.022	-0.041	8.8020	0.185
		7	0.005	-0.005	8.8096	0.267
		8	-0.050	-0.055	9.7098	0.286
		9	-0.071	-0.066	11.484	0.244
		10	-0.032	-0.014	11.849	0.295
		11	-0.028	-0.006	12.124	0.354
		12	-0.007	0.014	12.141	0.434

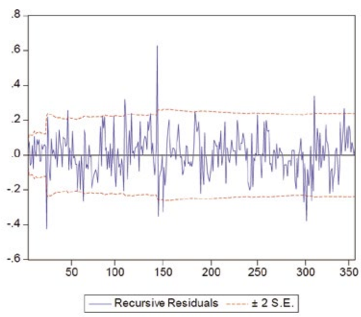

Figure A5. Guwahati–Shimla ECM

Sample: 2 356
Included observations: 340

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.086	0.086	2.5082	0.113
		2	0.082	0.075	4.7992	0.091
		3	0.122	0.111	9.9333	0.019
		4	0.040	0.017	10.490	0.033
		5	0.035	0.014	10.917	0.053
		6	-0.023	-0.044	11.093	0.086
		7	0.029	0.025	11.387	0.123
		8	-0.062	-0.070	12.755	0.121
		9	-0.115	-0.107	17.441	0.042
		10	-0.020	-0.001	17.578	0.063
		11	-0.075	-0.045	19.551	0.052
		12	-0.029	0.007	19.854	0.070

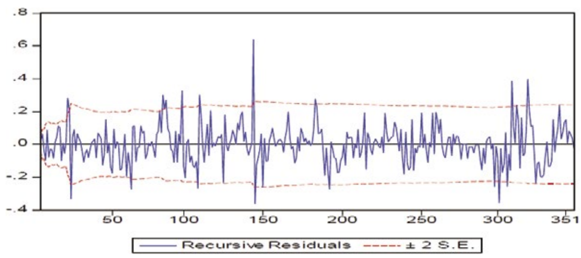

Figure A6. Guwahati–Hyderabad ECM

Sample: 2 356
Included observations: 342

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.079	-0.079	2.1601	0.142
		2	0.106	0.101	6.0836	0.048
		3	0.133	0.151	12.228	0.007
		4	-0.022	-0.010	12.391	0.015
		5	0.077	0.045	14.463	0.013
		6	0.068	0.065	16.095	0.013
		7	0.030	0.033	16.400	0.022
		8	0.023	-0.003	16.595	0.035
		9	-0.002	-0.024	16.596	0.055
		10	-0.026	-0.042	16.843	0.078
		11	-0.019	-0.034	16.966	0.109
		12	-0.015	-0.018	17.042	0.148

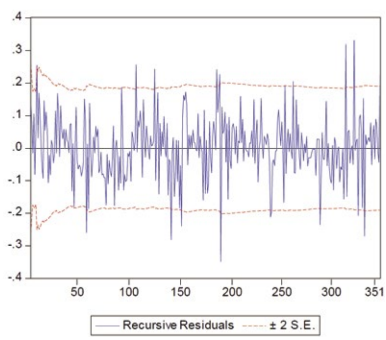

Figure A7. Hyderabad–Shimla ECM

Appendix B. Recursive ECM Coefficients

Equation 2 coefficients have following representation in the recursive coefficient Figures B1–B7:

$\beta_0 = C(3)$ regression constant
$\beta_1 = C(1)$ regression coefficient for differenced independent variable
$\beta_2 = C(2)$ regression coefficient for lagged error of the co-integration equation

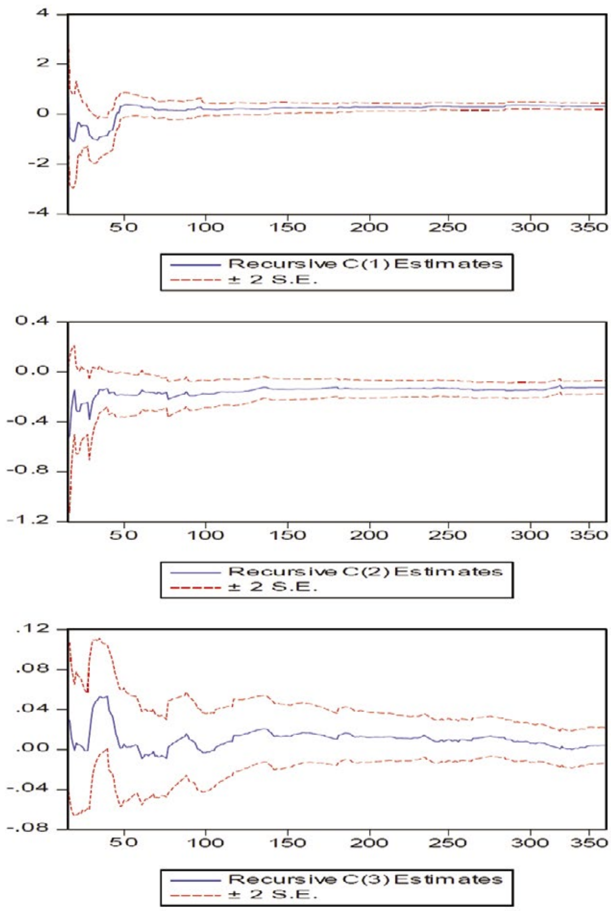

Figure B1. Agra–Shimla ECM

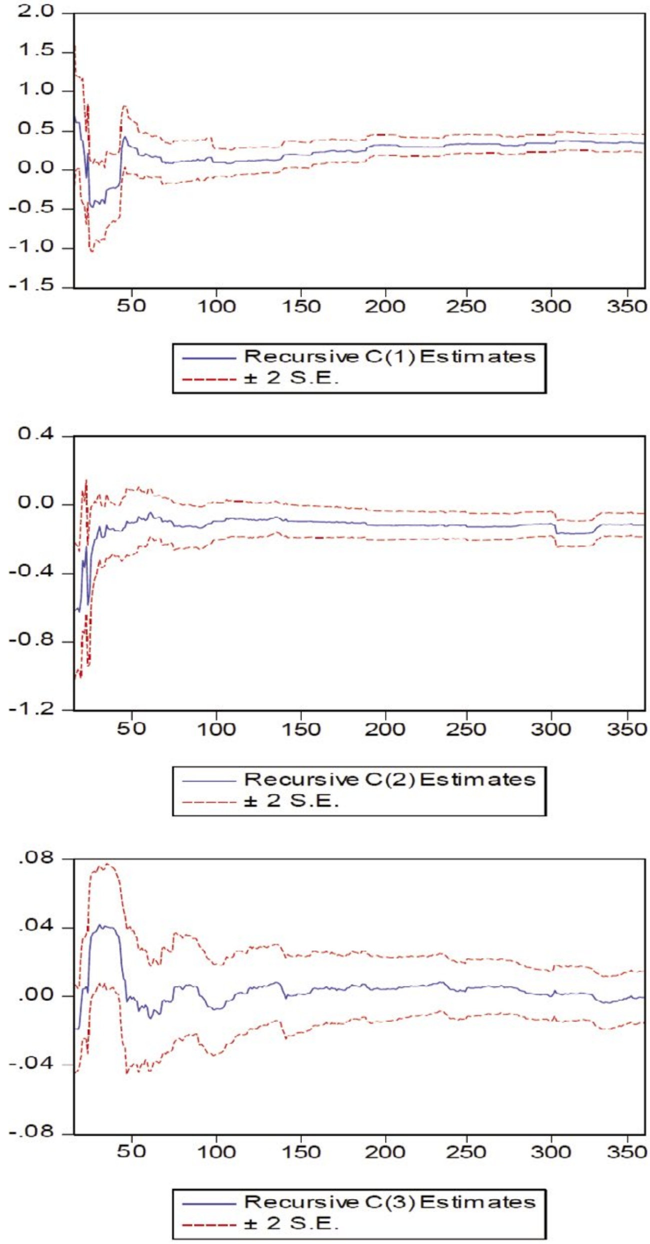

Figure B2. Delhi–Shimla ECM

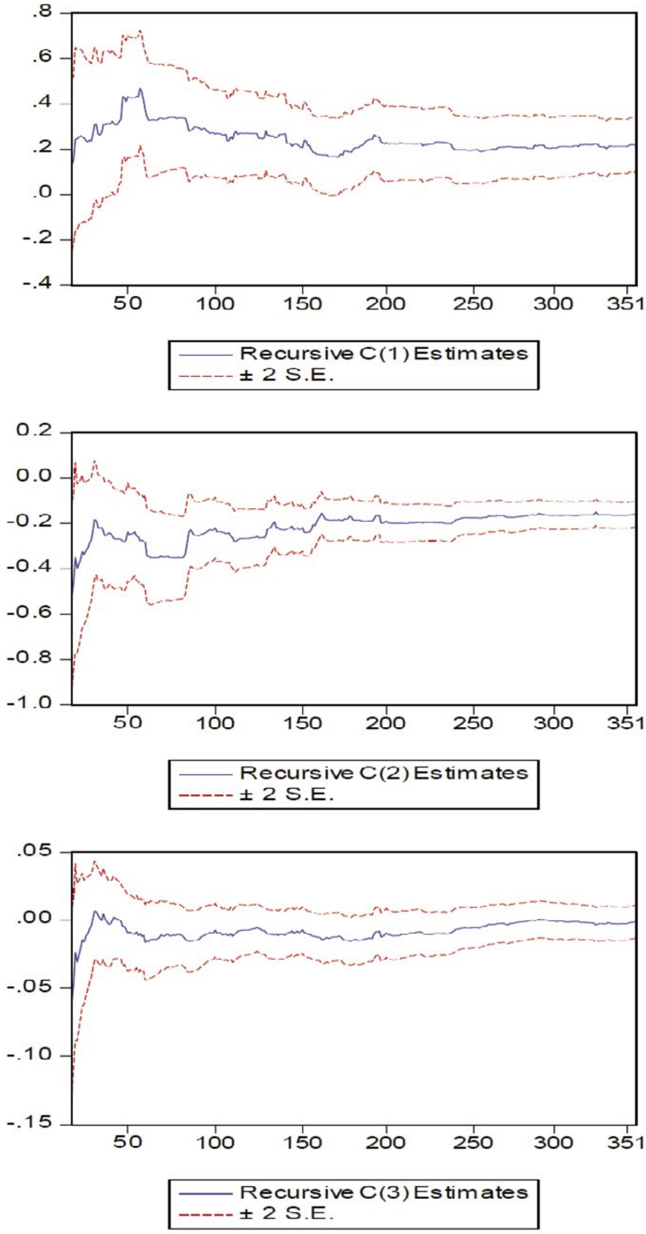

Figure B3. Bangalore–Hyderabad ECM

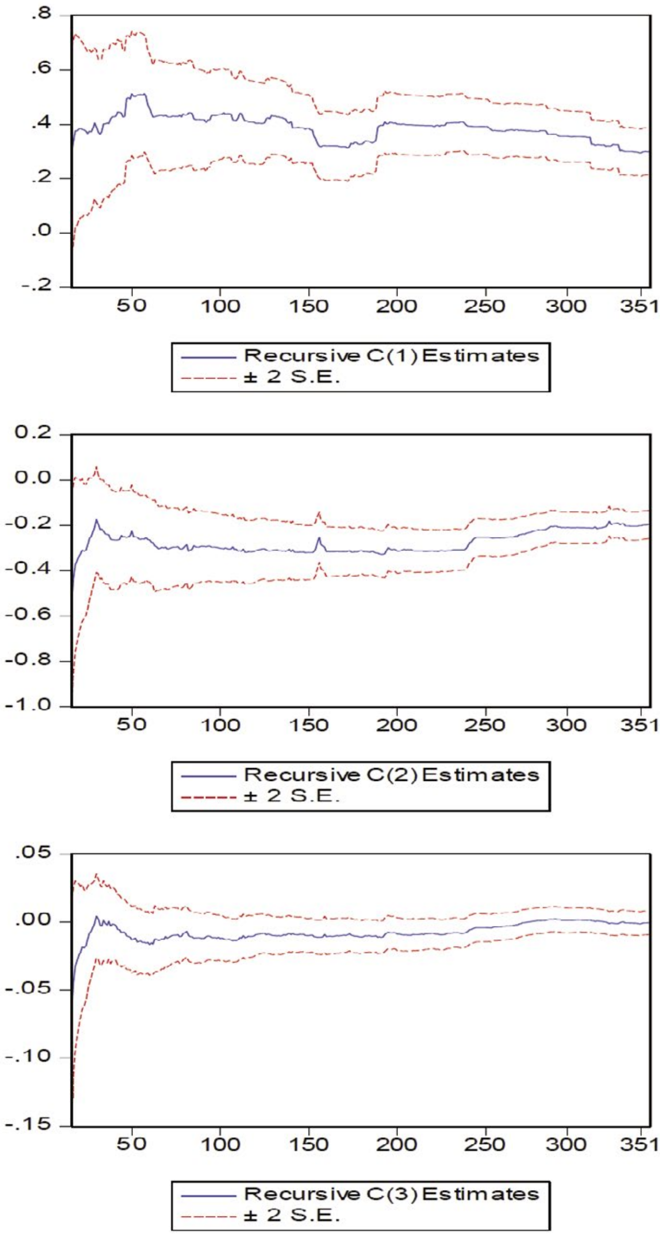

Figure B4. Chennai–Hyderabad ECM

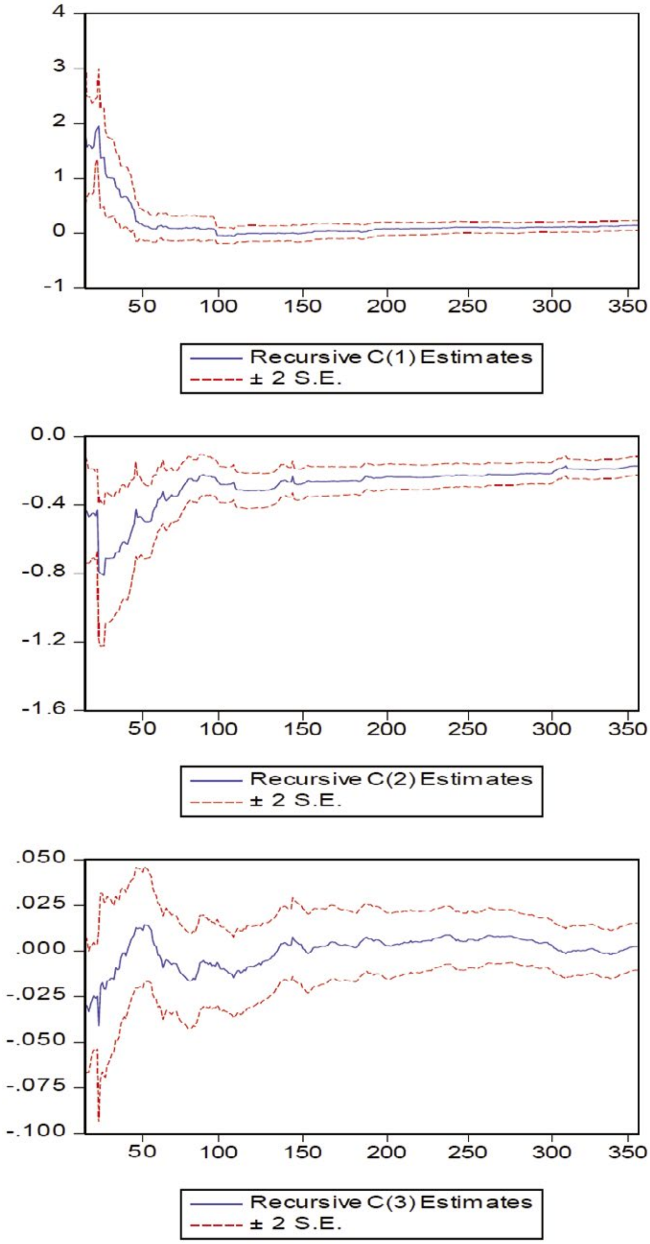

Figure B5. Guwahati–Shimla ECM

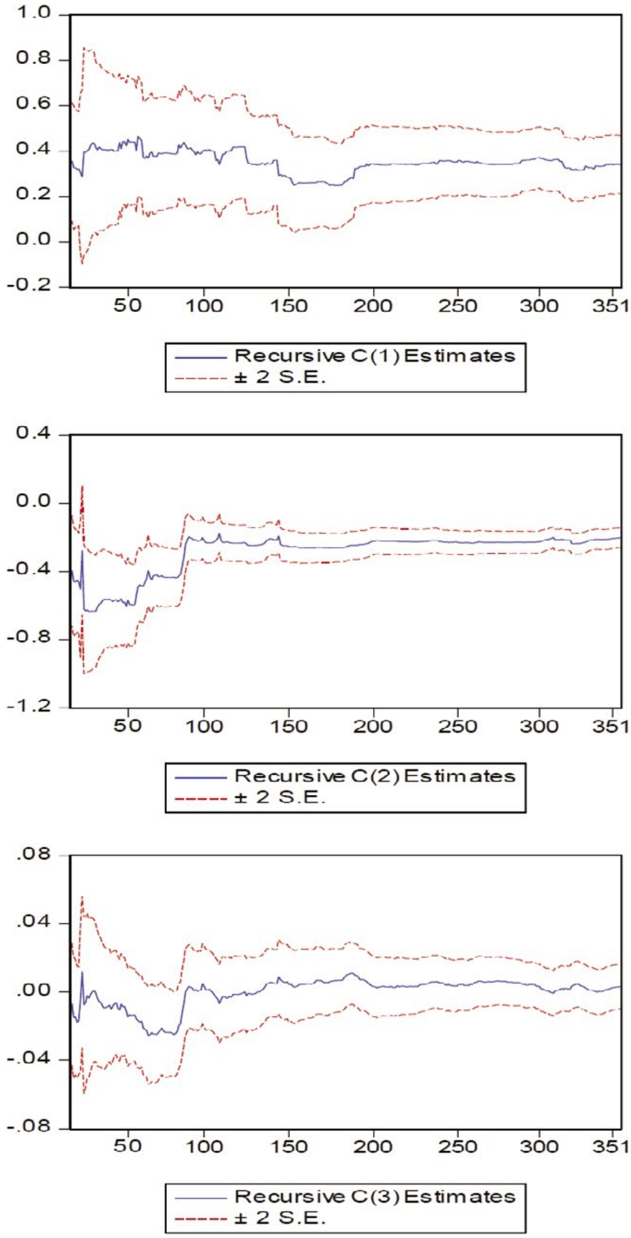

Figure B6. Guwahati–Hyderabad ECM

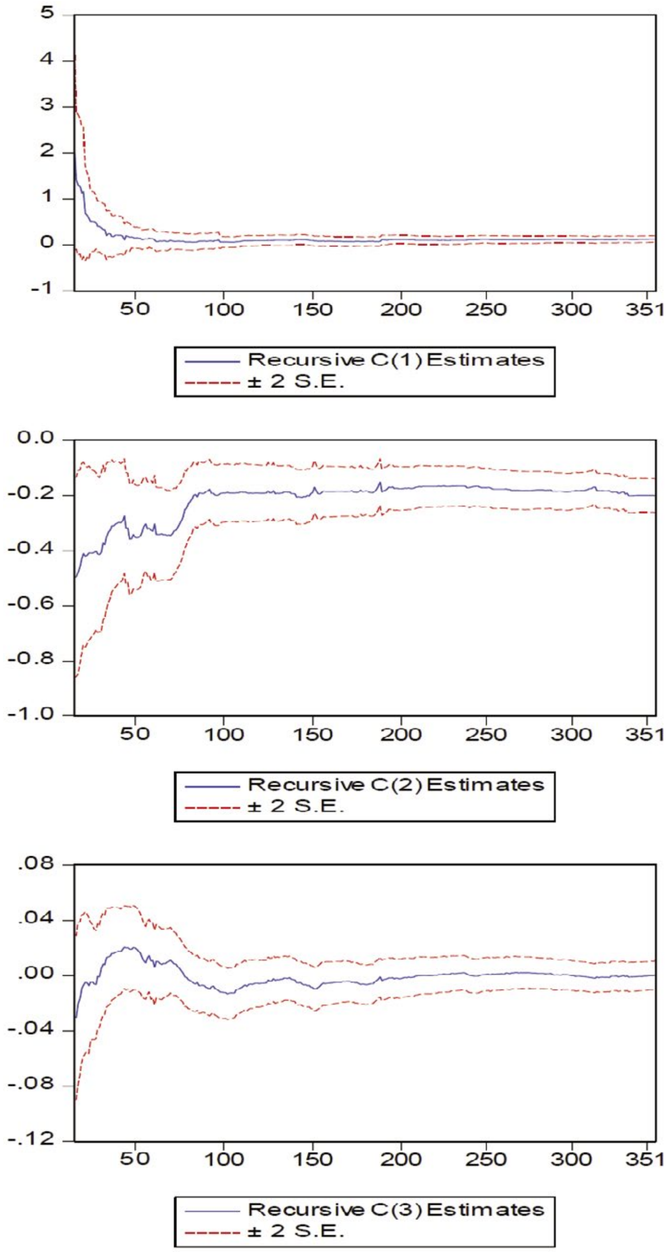

Figure B7. Hyderabad–Shimla ECM

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ARTICLE IV

O. Salmensuu, “Speculation in Delhi potato wholesale markets, 2007-2019: Causal connections of prices and arrival quantities,” *Cogent Economics & Finance* **8**, 1821997 (2020).

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Speculation in Delhi potato wholesale markets, 2007–2019: Causal connections of prices and arrival quantities

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Additional information is available at the end of the article

Abstract: This work built on financial literature on rolling window Granger-causality testing (RWGCT) methodology, specifically expanding its early theme of speculative trading which emerged in 2009 following the food price crisis. Although many times driving the commodity prices in reality, the unexpected often remains unexplained in equilibrium modelling. Financial speculation is a distinct, unexpected phenomenon which allows us to determine temporal order of affecting market forces in equilibrium dynamics. A logical framework retraces price and quantity adjustment directions from underlying speculative demand or supply curve shifts; using it, we extracted these shifts with RWGCT from the price and arrival quantity data of Delhi potato wholesale markets. The main results confirmed the framework, more speculation was detected on demand side compared to supply side. The food price crises of 2007–2009 and 2011–2012 saw most demand-side speculation, as financial liquidity poured also to potato markets, whereas supply-side speculation was most likely detected due to unexpectedness related to approaching harvest or its aftermath when considerably supply becomes available, and thus also greater potential gains from timing sales.

Subjects: Asian Studies; Development Studies; Financial Economics; Econometrics

Keywords: financial speculation; rolling window Granger-causality; food price crises; price and quantity; supply and demand; potato price
Jel classification: C12; C22; D41; D84; Q11; Q13

ABOUT THE AUTHOR

The author is finalising his PhD thesis in economics as an early-stage researcher at University of Eastern Finland (UEF). His research concentrates on potato prices in developing countries. He has previously worked as a researcher doing statistical programming at the Finnish Forest Research Institute (Metla, 2013–2014), statistician at UEF (2016), and as a specialist in economic and labour policy at the Blue parliamentary group (in the Finnish government coalition, 2017–2019).

PUBLIC INTEREST STATEMENT

This paper makes use of the rolling window Granger-causality testing (RWGCT) to detect speculation in financial time series. Trader speculation increases price fluctuation and overshooting which harms potato supply in India and in developing countries more generally. Easing potato supply would have positive effects for developing country urban conditions; curbing food price speculation would also improve particularly the profits of the poor farmers who often lack means of transport and post-harvest storage and thus have to sell their produce at low prices to better-positioned middlemen.

1. Introduction

Markets of finance attract interest in abundance and various specialist consensuses exist on factors affecting commodity prices. The research often constructs supply and demand equations for equilibrium model estimation, but quantifying temporally locations and persistence of these assumed impacts is hard. Partly the limits to estimation are due to complex interactions present in real world, requiring considerable consideration and wisdom of hindsight on anomalies to successfully model in econometrics as trade periods, areas, and items differ in characteristics. The likely reason for mixed evidence on a general theory of how prices are influenced by changing supply- and demand-side factors is often stated by adherents of the rolling window estimation; the relations between variables are not stable but variable in time. This paper describes in its introductory part how these complexities handicap equilibrium estimates particularly in the potato scene and then proceeds to illustrate how the rolling window Granger-causality testing (RWGCT) detects speculation in the equilibrium dynamics.

The main objective of the paper is to present a methodology, together with empirical data-driven results, for spotting periods of financial speculation from current high-frequency time series. The paper also aims to elicit discussion on the role of supporting statistical tests in choosing parameters for RWGCT, particularly as such tests penalise for lag length but are myopic to time which is needed for real-world market adjustments; this paradox results in overweight of low-frequency studies in published literature as the use of high-frequency series, which improves on accuracy, needs greater lag length for the same reaction time. The work contributes by proposing a general RWGCT framework for detecting speculation as a distinct economic phenomenon from unexpected shifts in supply and demand as they appear in competitive markets. Its empirical contribution is in detectable speculative action in the market studied, particularly in detecting food crises as major periods where demand side initiated speculative buying action. The results also imply that the Delhi wholesale market for potatoes is competitive, fitting into the framework which used RWGCT to detect supply- and demand-side speculation.

2. Potato supply and demand in India: few links to world markets

According to Timmer (2009, p. 14), in the short-run, price driving unexpectedness tends to be due to the supply-side behaviour for commodities for which inventory data are reasonably reliable, whereas commodities with poor data on inventories due to millions of small agents (farmers, traders, consumers) tend to have their price behaviour generated by rapidly changing price expectations themselves, with dishoarding and hoarding of the commodity. Although in commodity price and storage research the potato attracts little attention, we can reasonably expect that in developing countries generally—also in India—it belongs to the latter classification with unexpectedness in the short-run coming from both supply and demand sides. Even with all ongoing short-run action, the supply and demand for the potato is particularly local compared to many other food articles, which favours analytical frameworks for a single marketplace, such as RWGCT of prices and arrival quantities undertaken in this study. Also, when viewed from another angle, concerns on realism have surfaced with increasingly occurring applications of world market hypothesis to potato trade: "IMPACT model used [...] in the Global Futures Project incorporates the assumption of single world market for this commodity which is characterized by perfect price transmission and in which all country level prices are determined by a single world market price. Understandably we were somewhat unhappy with this assumption." (Kleinwechter & Suarez, 2013), and while continuing to analyse actual trade flows the study further notes: "India's trade is to a large extent limited to the island states of the Indian Ocean". For example, potato price in Finland (Jalonoja & Pietola, 2001) can hardly affect India due to institutional and competitive constraints, and the instability of Indian potato markets (Scott & Suarez, 2011, 2012). Thus also, as the IMPACT version used in potato supply and demand assessment for India (Scott et al., 2019a, 2019b) unhesitatingly connected with its system of equations to global trade 159 production land areas, not only Finland, great redundancy in potato trade route parameters ensued. More equilibrium modelling assumes parameters, even if the model is true, more likely are empirical problems due to collinearity, or by chance, some of the variables affecting others due to their statistical data properties only, consequently biasing and diluting true effects. Such concerns are too often ignored, particularly where results confirm general beliefs of the profession. It would be prudent to at least differentiate between developed and developing countries due to their differing economic structures, especially touching the cross-border trade of the bulky and perishable potato (Imai et al., 2017; Morshed, 2007; Prakash, 2008; Salmensuu, 2021; Scott, 2002), although no model that assumes a stable relationship between two variables can capture temporal connections between the variables, even though such are part of larger market chain consequences that lead to equilibria in market consisting of all goods and whole interconnected world (Timmer, 2009, p. 20).

2.1. Potato prices in Delhi

Much-emphasised rural-urban migration unlikely solves developing country problems without agricultural revival (Christiaensen et al., 2011; Haggblade & Hazell, 1989; Imai et al., 2017; de Janvry & Sadoulet, 2010; Johnston & Mellor, 1961; Rehman et al., 2016). Affordable year-round supply of potatoes to urban centres is a major aid to the poor and also instrumental for the success of continued urbanisation, such as occurred naturally, particularly during the 19th and 20th centuries in western temperate countries usually without preconceived administrative intentions, or through potato orientated agricultural planning such as recent times in China have now seen. Common to many developing countries, however, potato prices in India exhibit wide seasonal price fluctuation; ensuing price risk is a notable cost to potato dealers, resulting in high consumer prices. Price fluctuation also directly deters potato cultivation as poor producers, being constrained in means of storage and transport, are forced to sell at low prices.

The monthly potato report of the Indian government diagrammatically presents, of all the listed state-wise wholesale statistics, only Delhi prices and arrivals alongside whole India averages, underlining centrality of this marketplace. Still, despite their importance and data availability, studies concentrating on Delhi potato prices are relatively rare. Complementing price forecasting developments (Chandran & Pandey, 2007; Salmensuu, 2018), the present study contributes to price behaviour analysis through locating speculation in price series by RWGCT. The capital city area observes weaker marketing efficiency and slower areal price integration (Dahiya et al., 2002; Salmensuu, 2017) comparing to other Indian potato markets, which invites speculation and price overshooting, and ensuing political unrest. In addition to speculation in potato prices, onion prices are causing concern in India. Concerning these two vegetables of great political interest, the potato markets may be assumed to be competitive where hoarding and other speculative periods are received from the hands of millions independent agents, acting as a herd, whereas the onion markets are known for their high degree of cartelisation and price manipulation aimed to prevent entry of new players into the network (Fuglie, 1999; Madaan et al., 2019). Comparing results of this study to reactions by policymakers to speculation as covered by media, at least in regard to statistical significance, buffer stock policies appear promising in quieting demand-side speculation in potato prices (PTI, 2015).

2.2. Detecting speculation

In addition to instability of how and when variables are affecting each other, a distinct phenomenon for financial commodities blurs the matter further, i.e. speculative trading, which can move the variables farther from their natural relations. Rather than the forces of demand and supply bringing inevitably equilibrium price and quantity levels, in speculative trading environments the norm is breaking away from such equilibria. The study of temporal effects by RWGCT is gaining popularity nowadays in many financial applications. Its use format basically follows attempts in Robles et al. (2009) and Timmer (2009) to locate food price speculation due to other markets by inspecting how variable linkages evolve in time based on rolling Granger-test p-values. This methodology of graphical recognising and inference has thereafter also found non-agricultural implementations in modified forms using various interrelations between currency, commodity, stock and housing markets, energy and other consumption, national outputs (Aye et al., 2014; Chen et al., 2018; Fernandez-Perez et al., 2017; Tsai, 2019), etc. Much of this later literature replaces standard assumptions of asymptotic distributions with residual bootstrap techniques that may alleviate biases in small samples. Diminishing window (=sample) size is, at its best, still a trade-off that is aiming to possible gains in result representativeness at costs to test accuracy. Loss of accuracy is seen particularly from inflated significance limits; most of published RWGCT literature now uses low-frequency data, monthly or quarterly, and 10% significance, doubling the usual 5% limit. The availability of high-frequency data allows us to retain a high degree of accuracy, still representativeness in calender time matching above low-frequency studies. Continuing on the food price speculation theme, we preserve its earlier specifications, presentation techniques, and the common F-test methodology.

In this paper we develop a tool based on RWGCT for locating from time-series data approximate phases of speculative, unexpectedly occurring supply or demand shifts and for assessing their persistence in a commodity market having otherwise characteristic conditions of perfect competition that is often assumed for market models. Perfect competition provides structure that separates unexpected from expected concerning supply and demand movements. To improve our chances in detecting these short-run effects, this research is benefiting from daily data including arrival quantities, which provide a clearly distinguishable supply side. These modifications considerably aid RWGCT inference as we study the market forces behind the potato price formation in the very short run. How speculation as a distinct economic phenomenon can be used as a tool to detect unexpected supply or demand shifts is a notable difference to earlier RWGCT research that likewise built on the idea of spotting recognisable linkages from test result graphs. The methodological tool is likely useful in various markets for establishing similar causal evidence behind equilibrium adjustment mechanisms. Here, our actual results contribute foremost to the evaluation of local risks for potato wholesale dealers by locating speculation in time-series. Paying attention to and acting on potato price speculation is a little touched structural issue, which extends ramifications beyond dealers' potato marketing risks through the price system also to other levels; notably to consumer prices and potato use in urban centres, which is a time-tested key to successful urbanisation, and also to farm gate prices, affecting potato supply and partaking of the producers to profits. The research meets on-going needs, as many governments struggle with urbanisation issues and particularly the Indian government now aims at reducing agricultural poverty by doubling farmer profits by 2022, before the end of its 5-year term.

3. Data

The wholesale potato market data came from the National Horticulture Board of India (NHB). It contains daily fresh potato modal price quotations in Delhi wholesale marketplace from 11 October 2007, until 31 December 2019, and their corresponding arrival quantities. These series allow visually exploring statistical causalities between arrival quantity and price at particular time intervals. Four data points were removed due to apparent typing errors. All remaining price outliers lie in the interval of reported daily minimum and maximum. The price series was adjusted with Indian wholesale price index inflation. Figure 1 scatter plots the data. Typically, arrival quantity is 1000–2000 metric tons of potatoes in a trading day and a gap exists at about 600–800 tons, dividing arrival quantities into two clusters, separated by a vertical dashed line. The trading points are either equilibrium points or gradual adjustment points, before new equilibria, after some specific supply or demand schedule changes. An example with discussion of such adjustments follows in connection of Figure 2. The most important supply-related change is seasonal; the supply of potatoes in India is highest and prices lowest due to the main harvest. For illustration,

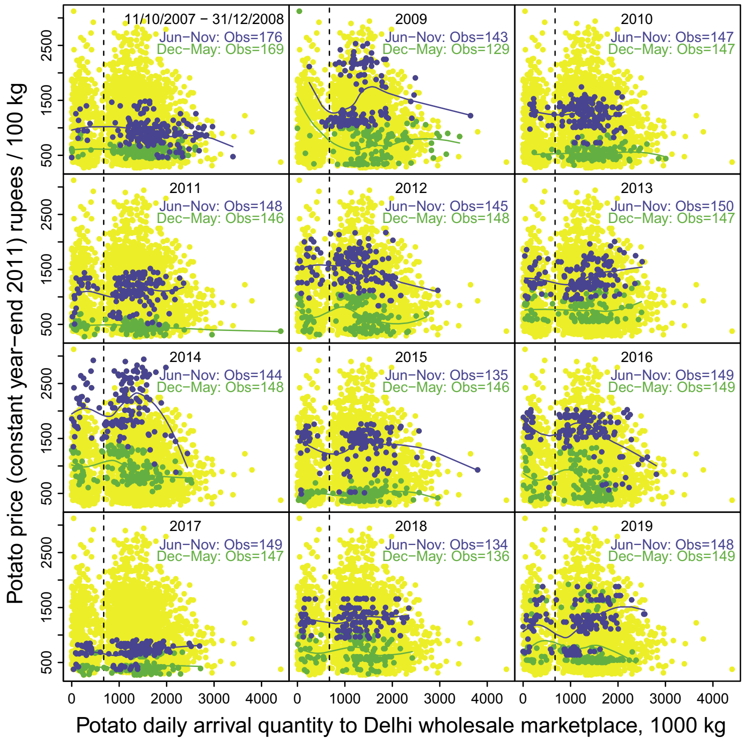
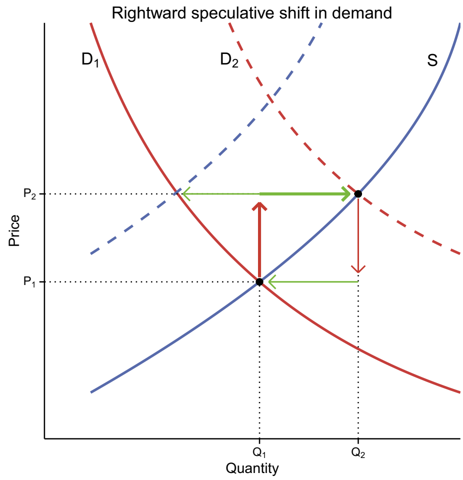


Figure 1. Cross-plots of potato arrival quantities and prices and seasonal loess curves.

the data set is split annually to its usual high-price and low-price seasons, June–November versus other months, i.e. January–May and December, respectively. Their loess curves in Figure 1 visualize that the price may stay markedly stable with regard to changes in the arrival quantity, but these two can also associate with a change to same or opposite direction.

The time series of price and arrival quantity appear alongside RWGCT results (Figure 3). Arrival quantities display notable variation whereas prices are generally more stable, comparing adjacent days. A notable arrival quantity change from the previous day usually brings no notable immediate price change or vice versa, implying that an adjustment lag exists. RWGCT inference in this paper is also validated by this observation, that fluctuation in arrival quantities causes trading parties no distress, as it supports perfect knowledge that is part of the perfect competition assumption. The earlier daily frequency RWGCT study (Timmer, 2009) used 15 days lag length and 6 months fixed rolling window size, and similarly we will have 15 trading days lag, and 150 trading days fixed window size which corresponds to approximately 6 months throughout our data. Spuriously statistically significant results due to overfitting occur in Granger-causality testing increasingly likely smaller the sample size. Nevertheless, researchers selecting lag lengths often use information criteria carrying penalty for lags, such as BIC and AIC, which leads to lag lengths of two and

Figure 2. Speculating on a supply (S) decrease, demand shifts from D_1 to D_2 with price-quantity adjustment following broad arrows. Narrow arrows depict return to normal demand with or without the supply shift leftward that buyers anticipated.[1]



three being common in literature (Bruns & Stern, 2019). This tendency in turn favours using low-frequency data and small sample sizes since the information criteria also make no distinction between frequency, e.g. whether data points occur hourly or monthly. This problem restricts studies in finance and other fields rich in high-frequency data, the information criteria are simply myopic to needed real-time adjustment lengths in potato markets in India. An early warning system needed 2–3 weeks of data for its over 60% accuracy in classifying between whether hoarding or weather affected prices, whereas forecasting accuracy still remained below 70% beyond few weeks when potato already requires cold storage (Madaan et al., 2019). It seems natural to use a real lag which approximately corresponds to Indian conditions and perishing of potato stocks without cold storage (Fuglie, 1999; Madaan et al., 2019) together with sensitivity analysis, acknowledging that adjusting reactions in physical markets are rarely immediate but require some time. The selected window size corresponds to maximal storage time of up to 5–6 months in India (Wustman et al., 2011; Madaan et al., 2019, the latter study also uses 6-month validation periods for anomaly detection). ADF testing rejects the unit root null hypothesis for both price and arrival quantity series even at 1% risk level using the chosen lag length. We therefore conclude that both series are stationary.

4. Methods

4.1. Supply and demand adjustments in speculative trading

Plenty of research on trading of financial assets exists. Literature, particularly on causality, price discovery and price–volume relationship for stock and housing markets, is wide and its methods numerous. In stock markets, price is often leading volume. In housing markets, where prices are more rigid especially downwards, the opposite is true (Narayan & Smyth, 2015; Tsai, 2018, 2019). This paper presents a tool based on RWGCT for understanding how equilibria are disturbed in speculative trading environments and how new market equilibria are consequently reached. Comparing to Timmer (2009), the early attempt to locate food price speculation by RWGCT of prices between various markets, we choose instead, in addition to prices, a direct measure of supply, i.e. arrival quantities. The logic behind this choice is simple and Tsai (2019) is closely related by applying RWGCT between American average housing prices and transaction volume. We use particular characteristics of NHB data to improve on general price–volume relationship assumptions; here arrival quantity is not only information on market conditions, it is actual supply that enters the market. Similarly to many other markets, potato wholesale sellers decide on the quantities that are sent to Delhi marketplace, or their speed, i.e. quantity per some time unit. And buyers correspondingly decide on the amount of money they bring to purchase potatoes. It is rather obvious that buyers are unable to directly influence the speed of arriving potatoes to the marketplace, but instead through lower or higher price bidding they signal changes in their demand. Similarly sellers have no direct influence on money or purchasing power directed to the market in question, but they can only decide their supply for the prevailing price level in markets of perfect competition. These market conditions should allow us to separate supply-led speculation from demand-led speculation by considering whether price or quantity was first-moving in processes leading to new price-quantity equilibria. Speculators enter the trade looking to profit from uncertain price action. Separating supply and demand sides is essential; sellers are on average closer to producer role compared to buyers. A producer is normally unable to sell his supplies speculatively in advance whereas a buyer may speculate by hoarding as price rises on a harvest delay.

In Figure 2, anticipating a supply decrease from S to the dashed blue curve, the buyers speculatively bid higher prices for their demanded quantities, and thus the demand shifts from D_1 to its speculative level, the dashed red curve D_2. Through this move speculative buyers receive potatoes at increased quantity and at a price that is still below their near future expected price. Price, that buyers can directly influence with their purchasing power, moves first in speculation, and quantity, that sellers by their possessions directly influence, then rationally adjusts to it, as depicted by the broad arrows, red and green. Speculators as a group are looking to resell the commodity. Exceptions exist. Some market participants on the buying side speculatively hasten or delay their intended purchase, similarly as sellers in the supply chain do hasten or delay their intended sale, but on aggregate we are justified in looking at buyer speculation by considering what happens when buyers succeed or fail to exit the trade with a profit. Optimally buyers succeed in reselling as their anticipated supply decrease materialises following the narrow green arrow at price P_2. Speculatively changed demand is of temporary nature. It will return to its original position as speculative buying no longer supports it. This return to normal does manifest itself in weakening of buying power, thus no longer supporting trade at P_2Q_2, the speculative equilibrium of greater price and quantity. In this weakening of speculative demand, price changes first and quantity then adjusts to it. The speculators who failed to exit their trades and are still looking for a suitable moment to resell the commodity face losses, depending on their individual entry and exit timing, but eventually the old equilibrium P_1Q_1 ensues as depicted by the narrow red and green arrows in Figure 2.

Above example of Figure 2 presents the most prevalent type of potato market speculation in India, i.e. potato price tends to go up when harvesting period is over and the commodity is hoarded expecting better prices, as recognised by trader agencies and research (Wustman et al., 2011, several other sources present without origin a similar list of Indian potato market affecting factors). Speculatively anticipating this seasonal supply decrease and its resulting price rise presents potential for hoarding profit even several fold of the original investment in a few months. This type of speculation appears most prevalent also in our present study, marked by blue-coloured dots of detected demand-side speculation, in the price and arrival quantity series of Figure 3 in the Results section.

Buyers anticipating a supply shift rightward and the two cases of supply-side speculation where sellers anticipate a demand shift are similar in their basic construct, merely requiring a little care for economic logic in modifications; only contrary to direction of Figure 2 arrows, supply-side speculation, being initiated by sellers, changes first quantity and then price. Noticeably, first-moving quantity change of a speculative supply shift may be retraced if speculators succeed in anticipating an upcoming demand shift. In Figure 2 example, the anticipated supply curve is found in the same general direction where also

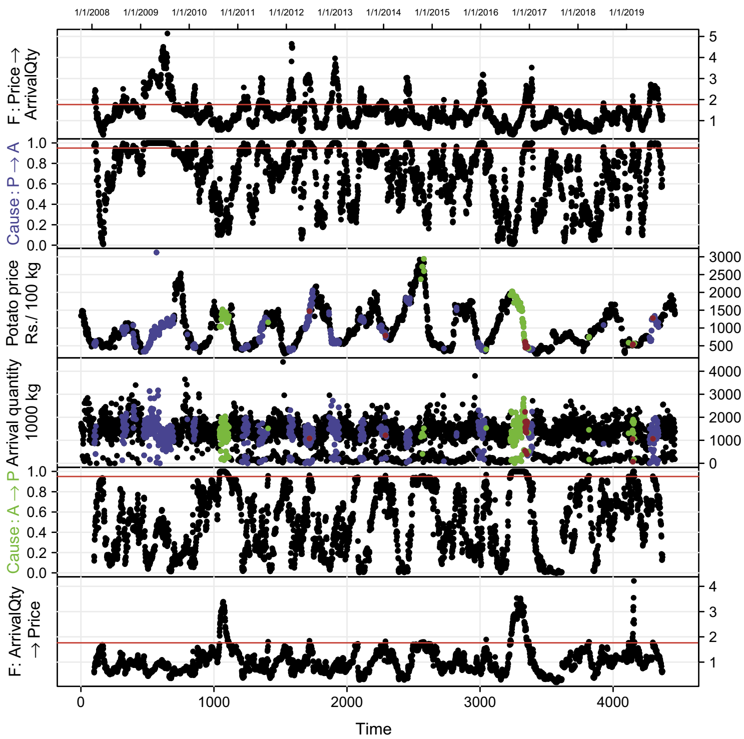


Figure 3. Rolling tests. Potato wholesale price in constant year-end 2011 rupees Granger-causing (→ , blue dots) daily arrival quantity to Delhi wholesale marketplace. Reverse causality, to price from arrivals, (←) is dotted in green. Two-ways causality (↔) is also dotted, but in brown, to price and arrival graphs. Parameters for window size and lag length: n = 150, m = 15.

first-moving price changes—upwards—whereas when quantity moves first, in case of supply-side speculation, it moves opposite the direction of an anticipated demand shift. This difference, derivable from asymmetry of market forces, makes lagged detecting of anticipatory supply-side speculation harder compared to demand-side speculation. Trivially, also simply note that speculative demand can anticipate real demand changes and similarly speculative supply can anticipate real supply changes. Also, speculation may anticipate that it will be followed by late-comers. In these cases, the speculative curve simply shifts towards its anticipated position, which will also result in quantity adjustment following price change or vice versa depending on whether demand or supply moved speculatively. Although the speculators may be incorrect in their anticipation of potential shifts, rational adjustment reactions to their speculatively changed schedules still occur. Concerning non-speculative shifts to supply or demand, they remain undetectable from lagged adjustments when market participants are informed and aware of events as they happen on both sides of trading.

4.2. Model of Granger-causality

Above, we described a logical framework for speculative demand or supply changes. Their market occurrences may be tested in Granger-causality regressions (Granger, 1969). Rational quantity adjusting, lagging behind a speculative demand shift, becomes visible from the testing result 'Price

→ (Granger-causes) Arrival quantity'. Similarly, rational price adjusting, lagging behind a speculative supply shift, becomes visible from the testing result 'Arrival quantity → Price'. Choosing a fixed time window and moving it after each estimation by one observation, until it has passed through the data from the beginning to the end, accomplishes rolling regressions between price and arrival quantity. This rolling method, RWGCT, distinguishes time periods where a variable is first-moving or lagging behind the other one. Granger-causality tests are applied to two directions for each of the rolling windows using the bivariate VAR model of Equations 1 and 2.

$$P_t = \alpha_0 + \sum_{j=1}^{m} \alpha_j P_{t-j} + \sum_{j=1}^{m} \beta_j Q_{t-j} + \in_t \qquad (1)$$

$$Q_t = \gamma_0 + \sum_{j=1}^{m} \gamma_j Q_{t-j} + \sum_{j=1}^{m} \delta_j P_{t-j} + \eta_t \qquad (2)$$

In these regressions P_t is the potato price at time t, the trading day in question. Similarly, Q_t is the potato arrival quantity at time t. Error terms $\in_t$ and η_t are uncorrelated. The number of lagged terms is denoted by m for both series, potato price and arrival quantity. This research applies rolling regressions with time window size $n = 150$ and lag length $m = 15$.

Concerning Equation 1, the joint significance of β_j coefficients is tested by the null hypothesis H_0: Q_t does not predict P_t if $\beta_1 = \beta_2 = \ldots = \beta_m = 0$, which implies *Granger-non-causality*, the lags of Q_t do not belong into Equation 1. The alternative hypothesis, H_A, for *Granger-causality*: Q_t does predict P_t if $\beta_1 \neq 0, \beta_2 \neq 0, \ldots,$ or $\beta_m \neq 0$. (Testing the joint significance of δ_j coefficients in Equation 2 has analogous hypotheses as above; δ in place of β and switching places for Q_t and P_t.)

F-test determines causality concerning Equation 1 (Equation 2 is analogous; for it $\in_t$ needs to replaced with η_t, and β_j with δ_j.) using residual sum of squares (*RSS*);

$RSS_{unrestricted} = \sum_{t=1}^{T} \in_t^2$, and $RSS_{restricted} = \sum_{t=1}^{T} \tilde{\in}_t^2$,

where in the preceding $\tilde{\in}_t$ denotes the error term that is received from the regression restricted not to include any terms with β_j coefficients, and T corresponds to the last time point used in the regression which number here $n - m$, after subtracting the lag length from the window size. We find statistical significance if the F-distributed test statistic (with m, T-2m-1 degrees of freedom),

$$F(m,\ T-2m-1) \sim \frac{(RSS_{restricted} - RSS_{unrestricted})/m}{RSS_{unrestricted}/(T-2m-1)}$$

exceeds the critical value at 5% risk level, or equivalently if p-value < 0.05; Gujarati (1995, pp. 620–623), Brandt and Williams (2006, pp. 32–34). We define, as Timmer (2009), causality as $cause = 1 - p$, where p means p-value of the F-test.

Each time window regression, of either Equation 1 or 2, or their restricted form, is a special case of linear regression. Their corresponding F-tests null hypothesise the non-significance of the predictors of interest. The test is therefore often called also Granger-non-causality. For simplified expression, this paper uses the term *cause* in the meaning that, in regression, inclusion of lags of the other variable does predict or Granger-cause the dependent variable. Similarly, these statistical significances in Granger testing are called demand- or supply-side speculation without always reminding of the above framework behind the thinking. We next proceed with RWGCT to answer two research questions related to Equations 1 and 2 compared to their restricted forms, respectively.

1. What do time periods where potato price causes arrival quantity reveal? Are they conforming to our explanatory framework of demand-side speculation moving prices first, followed by a rational adjustment in arrival quantity? Are causal patterns linked to particular price cycle phases?

2. Similarly, does inspecting time periods where arrival quantity causes price reveal something, and is this resulting view conforming to the explanatory framework of supply-side speculation? Can patterns be linked to price cycles?

5. Results from rolling window Granger-causality tests

With a total of 3529 data points for both price and arrival quantity, we rolled regressions forward using fixed 150 trading days window from data beginning to end which came after 3380 windows. Each window was thus tested using 15 days lag history in two directions of causality; first from price to arrival quantity, and then from arrival quantity to price. In Methods-section we related detected causal periods to speculation, the first initiated by buyers, i.e. demand-side, and the latter by sellers on the supply side. The presentation technique for results adopted from the earlier food price speculation themed RWGCT studies, which graphed F-series (Robles et al., 2009, F-test statistic) and *cause*-series (Timmer, 2009, *cause* = one minus p-value of the F-test) against the critical value, which is 0.95 in its inverse p-value scaling; both adhered to 5% risk level. In what follows, presenting same results in these two scales is beneficial for inspecting the details above and below the critical line.

Consider RWGCT results in Figure 3. The uppermost of its graphs presents Granger-causality test F-statistics compared against their critical value, which is the horizontal red line. When the F-statistic of a test rises above the critical line, we reject its non-causality null hypothesis at 5% risk level, concluding for this point that it presents evidence of 'Price causes Arrival quantity', which is demand-side speculation by framework set in Methods. The graph next below it, the second one from above, presents the same result in inverse *p*-value scaling, or *cause*. The last two graphs of Figure 3 present RWGCT results for 'Arrival quantity causes Price', which reveals supply-side speculation. The two middle graphs present prices and arrival quantities; coloured dots correspond to the middle of a rolling window that reveals speculation. As is now common in RWGCT research, each p-value corresponds to middle point of its test window. Most of the time, supporting perfect competition hypothesis, the dots remain black since the critical line remains unsurpassed. Causality from price to arrival quantity occurred in 643 tests (blue colour in Figure 3) and from arrival quantity to price in 186 tests (green colour). Of these two directions, in 20 test windows both occurred, thus indicating two-ways causality (brown colour replaces blue/green). Price-leading causality thus occurred thrice as often compared to quantity-leading; even so, in Methods-section we discussed that RWGCT has difficulty at detecting all supply-side speculation.

5.1. Testing 'price causes arrival quantity' for demand-side speculation

As discussed in connection of Figure 2 in Methods, RWGCT of 'Price causes Arrival quantity' can in a perfect competition environment reveal speculative demand shifts, affecting first price followed by rational arrival quantity adjustments by sellers on supply side. The most persistent period of demand-side speculation occurs during the 2007–2009 food price crisis. Substitute food prices increased due to increasing speculative liquidity, which also increased potato demand. Although potato price rise was modest in 2008 compared to 2009, the test results signal demand-side speculation already at early phases of the crisis; price was leading and arrival quantity kept adjusting with a lag. The 2011–2012 food price crisis pushed the F-statistic up again. The framework constructed in Methods appears correct; the food price crises intensified demand-side speculation, which is highly logical.

The cycles in causality were of special interest to Timmer (2009), which influenced the presentation technique in the *cause*-graph. It would be particularly rewarding, here, as well as for causalities from arrival quantity to price in the lower part of Figure 3, to solve the connection that affects cycle changes in different years. From price to arrivals, *cause*-series obeys cyclical movements as does potato price. Dissimilar to potato price, whose cycles follow annual potato cropping calender, in varying years cycles in *cause* switch to different positions; *cause* seems often uncertain on the direction of its next cycle and has often several ups and downs during one potato price cycle. Still, regularity is detectable. From 2011 until 2015, the blue colour particularly clearly phases into two intervals of annual price cycle, indicating demand-side speculation. Speculation is observable at near bottom prices or early price climbing periods and then again at higher prices ahead of main harvest. Food price crisis years of 2008 and 2009 witness these intervals also although extensions in periods of detected speculation make the intervals less separable from each other. Concerning remaining years, 2010, and 2016 onwards, studying the *cause*-series for details below the critical line reveals causal cycles that attempt to rise towards 0.95 particularly at each early climbing and also before tumbling without always succeeding. Although it appears that two phases of causal cycle occur during a potato price cycle, the evidence remains incomplete.

5.2. Testing 'arrival quantity causes price' for supply-side speculation

RWGCT of 'Arrival quantity causes Price' reveals unexpected supply shifts from the sellers. These speculative shifts start with sellers applying a change to arrival quantity which is followed by rational price adjustment from buyers, gradually reaching the new equilibrium; detected supply-side speculation is visible in the lower part of Figure 3, when F- and *cause*-series (the bottom and the second from the bottom graphs of Figure 3, respectively) rise above the red horizontal critical value line. Notably, arrival quantities cause prices statistically significantly only rarely. Comparing to demand side, RWGCT is weaker to detect speculative shifts on the supply side; this limitation was discussed in Methods. Nevertheless, the test statistics moved above the red line for statistical significance a few times; particularly three times at high prices in late 2010, 2014, and 2016, and also noticeably in early 2019. This last speculative spike appears as rising highest in F-statistic at the bottommost graph of Figure 3 and as green and then brown dots in the arrival quantity graph just above it. Perhaps also this last appearance of supply-side speculation attracted demand-side speculation, which during more tranquil time of two preceding years only shortly touched the limit for statistical evidence. On the whole, supply-side speculation should appear most likely with the availability of year-change main harvest supplies, in the wake of annually occurring price crash, as plenty of potato stock has become available and thus also greater profits from successful timing of sales. Traders are known to speculate by withholding their supply from markets particularly when they expect prices after post-harvest bottoming to soon start rising. But as speculating sellers are correct and prices soon rise, RWGCT is found weak in detecting this kind of speculation as discussed in Methods. Still we can see some green and brown at these low-price areas. Insufficient statistical evidence to confirm that seller speculation occurs every harvest period is undoubtedly due to the limits of RWGCT in detecting supply-side speculators when they succeed in anticipating upcoming demand shifts. Similarly two-way causality appears relatively rarely to detection although periods of continuing demand shifts such as food crises likely attract speculators from both sides. The supply-side speculation related cause-series appears as cyclical or counter-cyclical to price level, as was the case with demand-side speculation-related testing. Some of the cycles are comparably wider and even appear between silent periods when *cause* oscillates relatively low. Perhaps, after a speculative streak, which shifts the supply curve, many of the market participants become wary and prepare for its renewal. This wariness may discourage attempting similar speculation again with the next year's harvest. The buyers may also prepare faster price adjustment to regularly occurring speculative supply-side behaviour, leading to undetectability in our statistics which extract adjustments which are lagging behind a speculative shift. This explains also why causal cycles sometimes switch direction; market participants update their behaviour based on previous experiences.

6. Robustness

A major limitation of RWGCT is generally in multiple testing issues, i.e. no correction is applied for testing adjacent, often very similar windows. When few observations shortly only touch the limit of statistical significance, refraining from offering any special interpretation on them would be conservative and good, acknowledging the multiple testing limitation. By a random chance of 1 in 20 such single visits above the limit occur. This is another aspect that speaks for robustness of our main results; they display convincing persistence and logic instead of short visitations above the statistical limit. In comparison much RWGCT literature uses even inflated 10% limit instead of 5%, and thus often makes strong inference even on solitary points of observed causality that occur with a random chance of 1 in 10. In addition, sensitivity analysis is often neglected. Strong results may be confirmed by sensitivity testing with alternative parameters. We performed sensitivity checks ($\pm 20\%$ variation in window size and lag length in Figures 4 and 5) to verify Figure 3 of the Results section.

6.1. Sensitivity checks

Instead of n = 150 window size and m = 15 lag length specification, which was presented in Figure 3 of the Results section, Figures 4 and 5 run same procedures using alternative parameters. In this study, these parameters (n = 180, m = 18; n = 120, m = 12) naturally correspond to sensitivity checks for $\pm 20\%$ movement in both window size and lag length. Sensitivity testing confirms our main results. The overweight in detected demand-side speculation compared to supply-side speculation appears also in sensitivity testing, particularly during the food price crises, while supply-side speculation is most likely detected in the proximity of a new harvest and its supplies.

7. Discussion

In this paper, RWGCT demonstrated its capability to detect financial speculation from time-series price and quantity data and relate it to either demand or supply side, depending on whether quantity adjustment was lagging behind price change or vice versa.

7.1. Findings

Demand-side speculation was strongest during the food price crises of 2007–2009 and 2011–12. The crises attracted speculative money to food commodities, and increased their prices generally. This trade environment increased naturally also potato demand due to substitutability of food articles. Supply-side speculation was rarer and most likely detected at high prices nearing new main harvest—possibly early, unexpected shipments directed from other markets. We also detected some speculation at lower prices, which empirical result is logical and known by practice, as potato traders, according to their possibilities for storage, tend to postpone sales during post-harvest period in the anticipation of later on receiving higher prices.

Two phases of annual potato price cycle seem to be particularly linked to speculation. The first phase occurs at low prices, before major price rising, particularly as the demand-side speculators wish to enter their trades hoping to profit from price run-up, or supply-side speculators withhold from selling for same reason. The second phase of speculation occurs at near high prices or as prices start to fall, as potato buyers postpone purchases or earlier speculatively held positions are exited in the anticipation of price fall. Some of the causality that is detected at higher prices may be due to unexpected levels of inventory. Also, at price cycle top or near it, as potato storage is being emptied, unexpected shifts in supply are more likely to be responded by buyers through price adjustment immediately, which hinders the detection of speculation by the lag-based method used in this study. All in all, detecting that causal cycles clearly and continuously would be linked to potato price cycle was impossible. Rather the cycles seem to live a life of their own, likely due to continuously changing expectations that answer to speculative behaviour. Inability to establish two phases of demand-side speculation for each year up to the evidence of the critical line is no surprise; at least partial independence of the annual price level cycles from causal cycles confirms that market participants

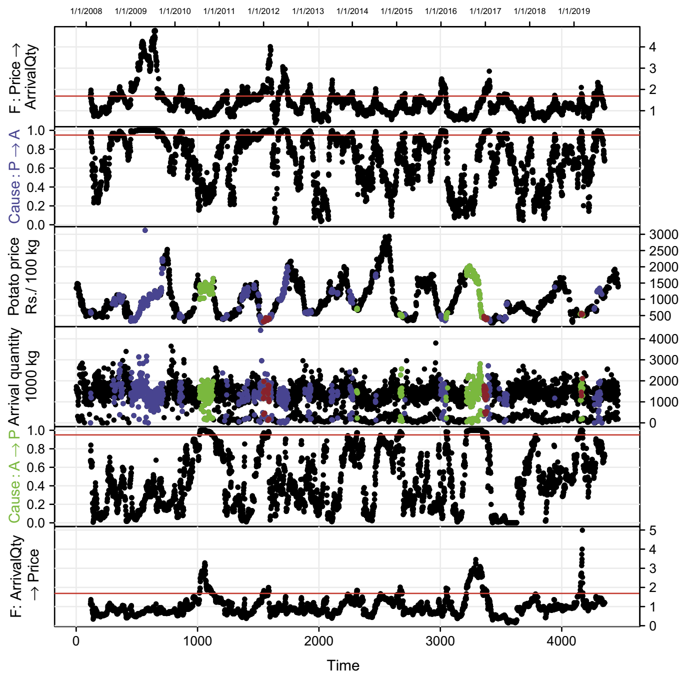


Figure 4. Rolling tests. Potato wholesale price in constant year-end 2011 rupees Granger-causing (→ , blue dots) daily arrival quantity to Delhi wholesale marketplace. Reverse causality, to price from arrivals, (←) is dotted in green. Two-ways causality (↔) is also dotted, but in brown, to price and arrival graphs. Parameters for window size and lag length: n = 180, m = 18.

are generally expecting the elements that make price cycle; harvest supplies and post-harvest adding storage costs and running out of potatoes. A cob-web type behaviour in market participant wariness or changing expectations in response to earlier speculation likely exists. When speculation is becoming more expected at certain interval, its profit potential and temptation weakens. Also, RWGCT is weak in detecting supply-side speculation where the initiating quantity change is retraced if it is successful in anticipating demand shifting. This methodological feature also generally explains greater occurrence of demand-side speculation, compared to supply side. Demand-side speculation overweight in the results for its part indicates correctness of our prescriptions concerning temporal order of price and arrival quantity movements in Methods-section, test result inference, and that RWGCT can bring visible speculation in the wholesale potato markets in Delhi.

7.2. Comments

Comparing to the early high-frequency study on food price speculation (Timmer, 2009), which also detected speculative cycles of changing expectations, an important difference is that instead of linking two markets (oil, rice, currency prices), this study concentrated on a single market and data that was separable for both sides of the trade. The arrival quantity data allowed added structure to RWGCT and thus made feasible inference on supply and demand roles and their comparison to occurring potato price phases. In addition, thanks to the structure provided by the potato markets and other advantages, this study could devise some rules on the likelihood of speculation. Comparing to recent low-frequency monthly housing market studies (Tsai, 2018, 2019), where price data were paired with transaction volume bearing similarity to present research, RWGCT results are revealing markets' conditions; economic shocks of unsteady market climate or speculation.

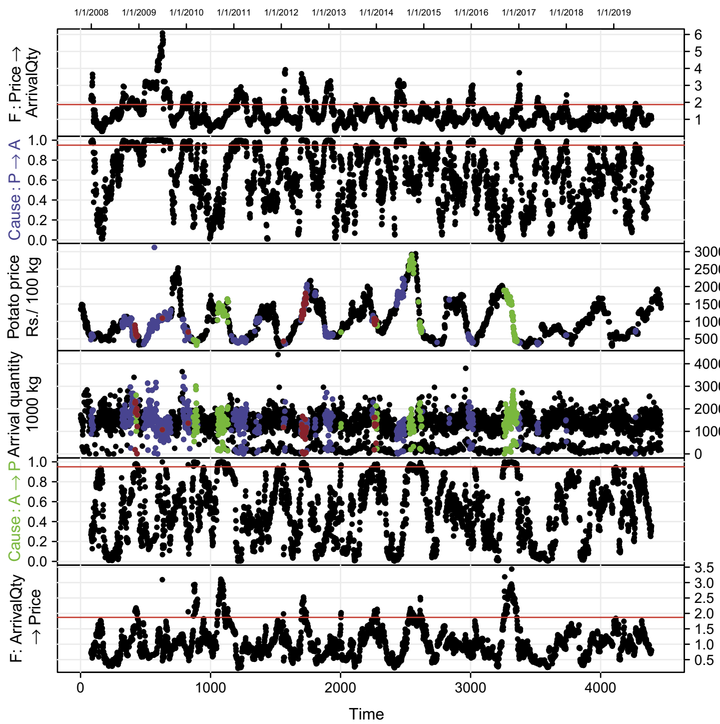


Figure 5. Rolling tests. Potato wholesale price in constant year-end 2011 rupees Granger-causing (→ , blue dots) daily arrival quantity to Delhi wholesale marketplace. Reverse causality, to price from arrivals, (←) is dotted in green. Two-ways causality (↔) is also dotted, but in brown, to price and arrival graphs. Parameters for window size and lag length: n = 120, m = 12.

Perfect competition, a common assumption in market models, makes all market participants price takers. Although individual traders on both sides of the market in such environments have no power for market manipulation, they may and often attempt to time their sales and purchases. These attempts to guess near future market movements then lead to a departure from the prevailing market equilibrium as many market participants, without any agreements made between them, either as buyers or sellers, deviate from their rationally expected roles. Speculative sellers, deviating from their rational supply schedule, can directly affect quantity of merchandise supplied to the marketplace, whereas similarly buyer speculation can through money or buying power directed to the markets affect demand only, causing speculative prices of the available merchandise. After either one, price or quantity, has speculatively changed in a shift of demand or supply, the other one, quantity or price, which is still lagging behind the first-mover, is adjusted rationally by the other side of the trade. These unexpected shifts offer the methodological basis for detecting speculation from lagged responses by RWGCT of price and quantity in perfect competition environments where a temporal lag between observed price and quantity changes is quantitatively distinguishable. The potato's wholesale marketplace in Delhi allowed added structure, markets of perfect competition, and also provided daily arrival quantity and price data in sufficient frequency for detectability of lagged responses. These structural and data advantages benefited the framework which acted in this study as a solid basis for RWGCT inference and served for spotting instances where speculative shifts to supply and demand are at work. For selecting and testing alternative markets, similar feasibilities should be evaluated; proper parameters, variables and also nonlinear functional forms, will likely bring related knowledge on the topic of financial speculation.

For the potato in developing countries, the effects of food price speculation manifest themselves in high consumer prices but also low profits for growers who are due to lacking knowledge, capital, storage technologies and infrastructure worse positioned compared to wholesaler dealers for the business of storing and trading large quantities. Thus, although unexpected dishoarding and hoarding of the commodity by traders, which further ignites price fluctuation and overshooting, adds to both positive and negative risk of the speculators, it has often plainly detrimental effects to potato use among the urban poor and livelihood of farmers. Seller speculation aiming to profit from the usual price cycle is well known, and also buyer speculation since the opening of futures trading for potatoes has been widely discussed. Apart from allowing an added vehicle for speculators, futures trading provides an opportunity to settle prices in advance for large suppliers, which helps reduce future possibilities for price variation, thus also reducing elements which draw speculators to the potato.

For policy, partly already publicity of speculative holdings that are approximately detected through storage registers or analytical frameworks such as developed in the present study should increase adjustment efficiency, discouraging particularly harmful speculation that receives its profits from unexpectedness and lack of market efficiency. With such knowledge, also dynamic policy that directs supplies of food or buying power to markets where prices are in a speculative state becomes an option. It appears that policies planning for buffer stocks to counter speculation in Delhi potato prices discouraged demand-side speculation as less of its evidence is detectable, i.e. blue-coloured dots which mark visits above the limit of statistical significance in Figure 3, in a few years since their media reporting (PTI, 2015). Knowledge and actions which for their part lower risks in potato holding and its middleman margins hold the promise of greater supply of affordable potatoes to retail consumers also in urban Delhi and a greater share of potato income to its producers.

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Note
1. There are helpful internet resources (pages accessed 11.9.2019) for drawing such figures; http://stats.stackexchange.com/questions/380772/supply-and-demand-graphs-in-r/380797 directed my attention to http://www.andrewheiss.com/blog/2017/09/15/create-supply-and-demand-economics-curves-with-ggplot2 that provided code for the graphics, with some alterations.

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correction
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POTATO PRICE FORECASTS IN DELHI RETAIL FROM BAYESIAN REGIME SWITCHING

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Abstract

A Bayesian regime switching model for month-ahead forecasts of potato price in Delhi retail trade is constructed. The monthly crashing limit is set to -10 percent. The price crashes annually due to main harvest, starting in either November or December. Using same limit, either January or February is still crashing in the harvest aftermath. The regime switching both at the beginning and end of the crash is thus a Bernoulli trial that here updates conjugate Beta distributions. Same structure for Bayesian learning is set also for crash oscillations between lower and upper bottoms with Markov Chain dependency on the previous bottom type updated probability. Rising of the price in between the crashes is implemented by conjugate normal distribution and previous month data.

1. Introduction

Following [6] it has become usual to use ARCH and GARCH for modeling financial time series. They allow the variance of the error term to depend upon its past. Especially for high-frequency modelling this holds an appeal, since very big and fast movements can bring volatility. The models

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have also been applied on potato prices, a recent example is from US markets [2]. For more examples on ARCH and GARCH implementations, see for example [3, pp. 478-494]. This approach, that has become conventional, is not optimal for monthly retail potato price modelling in Delhi. The price speculation in Delhi potato markets may persist to disturb usual market dynamics and weaken market integration with rest of India [12]. It is also known that retail pricing is different from wholesale pricing [11, pp. 353-357]. The retail price is normally slower to change downwards and may hold steady after a strong price movement upwards even though the wholesale price might have started to retrace much of its price advance. The big price movements that are anticipated to happen in a certain time range can often be also followed by consolidation periods where volatility is not increased. This tendency of added retail price stability is even more emphasized for monthly frequency that we have. Due to these general characteristics, Bayesian learning based modelling with regime-switches set up in accordance also to particular seasons holds an appeal.

In another approach, a seasonal ARIMA or SARIMA model was built to model monthly Delhi potato wholesale prices in [4]. Although some of the years are predicting occurring prices very well in it, we wish to improve on prediction realism, seeing from the model fit and price history graph provided that the model fit is much more likely to follow price than precede it. That is, when price is rising, the prediction error tends to be negative, and vice versa. This tendency in the model is seen also in its specific forecast provided surrounding the main harvest time from October 2005 until January 2006. The forecast is below actual price as price is rising, until December when crashing starts, thereafter it is above it. We would also wish that the model retains forecasting ability but whose forecasting error would be as much as possible independent of price trend or price level regimes. We will concentrate on one-month-ahead forecasts. Also [5] has its modelling focus on one-period-ahead expectations of price. A tailored forecast model for retail potato price in Delhi has been missing that would take into account the specific characteristics related to the harvest period and speculation driven price movements in retail price setting where ARCH and GARCH have limitations.

The potato price formation and the slope coefficients in the price cycles can be varying in different years but still contain elements that are highly expected. Therefore the Bayesian modelling with posterior updating occurring from the latest data and prior information can be a more successful solution than the usual likelihood modelling. Given independent and identically distributed (i.i.d.) sample data $D_n = y_1, ..., y_n$ from a density f_θ with an unknown parameter $\theta \in \Theta$ (for example in case of normal distribution, $\mu \in R,$ that is unknown mean μ being from the real line R), the likelihood function is written $l(\theta | D_n) = \prod_{i=1}^{n} f_\theta(y_i).$ According to Bayes theorem, this can be modified into posterior distribution, $\pi(\theta | D_n)$, which is a probability distribution on Θ, using prior distribution $\pi(\theta)$ that summarises prior information on θ, thus $\pi(\theta | D_n) = \dfrac{l(\theta | D_n)\pi(\theta)}{\int l(\theta | D_n)\pi(\theta)d\theta}$ [8, p. 19].

In this research, the prior distributions to be used are conjugate. So their posterior distributions represent same distribution type as the prior. Normal prior will transform into a normal posterior as data comes from a normal distributed process, in this research the potato price growth rate. Beta prior will transform into a Beta posterior with data coming from a Bernoulli process. A quickly updating Bayesian regime switching price forecast model will be built with the aim of taking into account specific characteristics of Delhi retail markets. These are rampant speculation caused by short-run food hoarding during price climbing periods, post-harvest price crashing months, and anticipation of eventual price tumbling at high price cycle. The data is much affected by the Indian main potato harvest, the autumn crop, that is planted annually in August-September and harvested in December-January. The regime switch to turn the rising potato price trend into a tumbling one can be built around this harvesting time. The two other but smaller Indian subcontinent potato crops, the spring crop and summer crop that have their respective harvesting times in May-June and August-September have their own separate regime switch coded in the model but with greater simplification.

2. Data

The data [7] concern the monthly real retail price for potato in Delhi for years 2000-2012. The preliminary study of the trade history revealed that the price has its intra-year high in the month of October with frequency 8/12. Correspondingly the intra-year low price is in February with the frequency 8/12. In 2009 the potato price was higher than normally due to the world wide food crisis. Even then the price dropped sharply at the main season harvest time. Figures 1 and 2 present the potato real price and its logarithm. The tumbling of price during the harvest in November-December seems to be very straightforward. On the other hand the rising part of the price cycle is more varying and contains plateauing periods. Figure 3 presents monthly changes to logarithmic prices.

The monthly price differences give a natural starting point to define the crashing of price and its modelling. A limiting horizontal dashed line at -0.1 to define a crashing month has been drawn into Figure 3. The price does not go below it except in months of crash. Therefore the annual crash or tumbling of price may begin in November when about half of the years of data the negative change in price from the October price was more than 10%. In any case the tumbling of price eventually happens and in all years deepens in December to be greater than other crash months except for February 2009. In January, the percent drop is smaller when compared to December. January can be seen as a crash month even though one change in price is slightly above -10% limit. February is a possible month for the crash still to continue. October is not yet a harvest time crash month and March is no longer harvest caused crash month. The slight correcting of the price downwards is possible also during other months. Price decline happens sometimes during other months also except for June when prices increased at least 7% every time in this data. The new main harvest caused price crash happens therefore during the interval November-February. The crashing starts by the negative price change of November or December and finishes by the change of price in January or February. The December tumbling of price is seen deepest for each year in the monthly price difference Figure 3, the exception to the rule being February of 2009. The greatest rise in price on the other hand happens usually in June. The Supplementary Appendix Figures S1-S3 present monthly histograms and also joined histograms for 4 price crashing months and 8 price rising months. Month specific observations of price change may come from the normal distribution. For joined histograms it is to be noted that separate months have very different means and standard deviations of the distribution. The differing between months of the expected monthly price differences is seen from Table 1 which shows also the standard deviations.

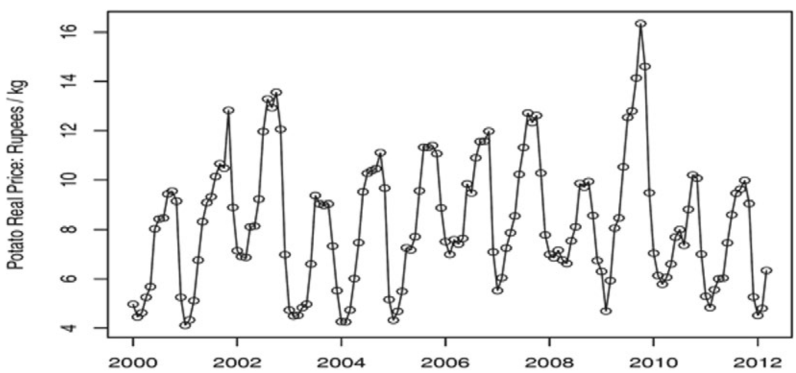

Figure 1. Real price, January 2000 - March 2012.

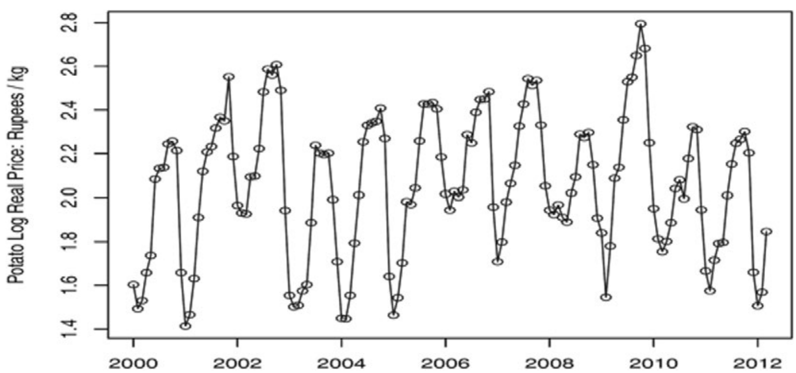

Figure 2. Logarithm of real price, January 2000 - March 2012.

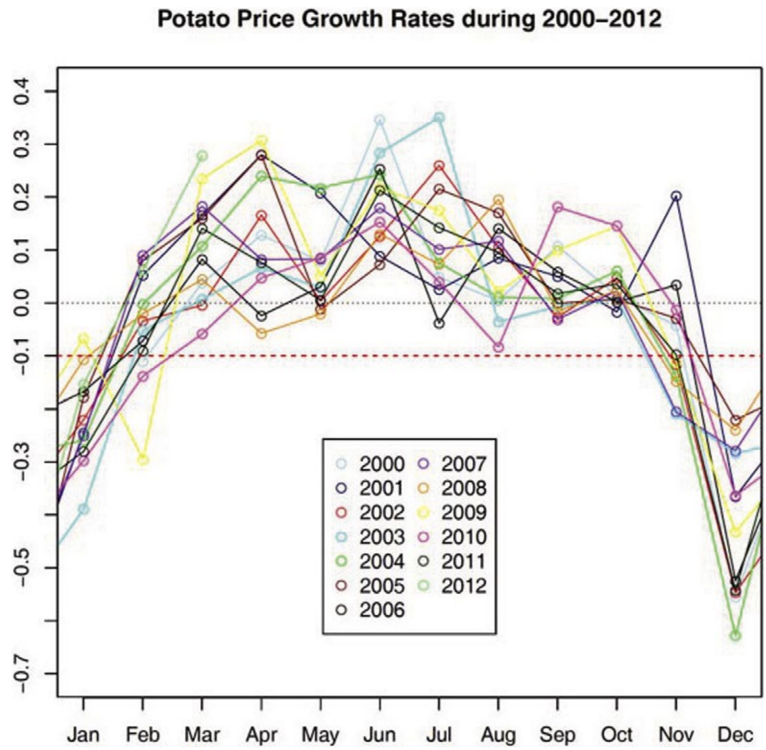

Figure 3. Monthly logarithm change.

Let us first study the standard deviations of the monthly price changes. Roughly simplifying, after the price crash ends by January or February still tumbling the standard deviation falls from 0.1 eventually to 0.05 after which it jumps in November to 0.1 anticipating or starting a new tumbling. For simplicity of the modelling the standard deviations of the price tumbling months can be kept unchanged at 0.1 although December has in the data somewhat higher value for it. The 19% average rise in price in June with modest standard deviation is marked comparing to other price rising months. June is in the data the only month where prices always rise. Notable is also the marked slowing of price rise starting from August accompanied with lowering of the standard deviation. Of the price crashing months December can be roughly estimated to take 60% of the full main harvest related tumbling; we may count average price change of the two possible crashing months February and November as one month.

Table 1. Means and standard deviations

	Mean	Standard deviation
January	-0.218	0.089
February	-0.041	0.106
March	0.106	0.100
April	0.132	0.122
May	0.063	0.079
June	0.192	0.082
July	0.122	0.111
August	0.069	0.085
September	0.037	0.065
October	0.041	0.053
November	-0.073	0.114
December	-0.415	0.142
Rising	0.095	0.100
Crashing	-0.184	0.186
All	0.002	0.188

Let us take into consideration the above characteristics of the data in building the model. But we also need to set up the mechanism for the price bottom into which the crashing ends annually after the main harvest. A great part of potato growers is dependent of the annual bottom prices for their income and their interests to increase or decrease potato cropping areas should then reversely depend on previous year bottom price. High producer price at previous year would then tend to translate into high production and low producer price for the following year, and vice versa. Such oscillation around the mean producer price is well-known as cobweb phenomenon, and due to its applicability to agricultural commodity prices, has been studied extensively. For a formal exposition of the theory, see for example [10].

Our data on annual bottoms, which are times where most producers are selling their crops, has only few observations so drawing conclusions on the shape of the distribution based only on them would be hazardous. The annual bottom prices as histograms in Figure 4, however, seem to indicate that the bottom comes from two separate distributions, which is in line with the cobweb theory. Let us suppose that these two are normal distributions. The lower bottom distribution based on histograms, data mean and standard deviation is in logarithmic prices $N(1.5, 0.05^2)$ and similarly the upper bottom distribution can be chosen as $N(1.85, 0.1^2)$. A sensible way to decide from which of these two distributions the new estimated bottom will come from is to allow the probability and choice be dependent on the location of the previous bottom.

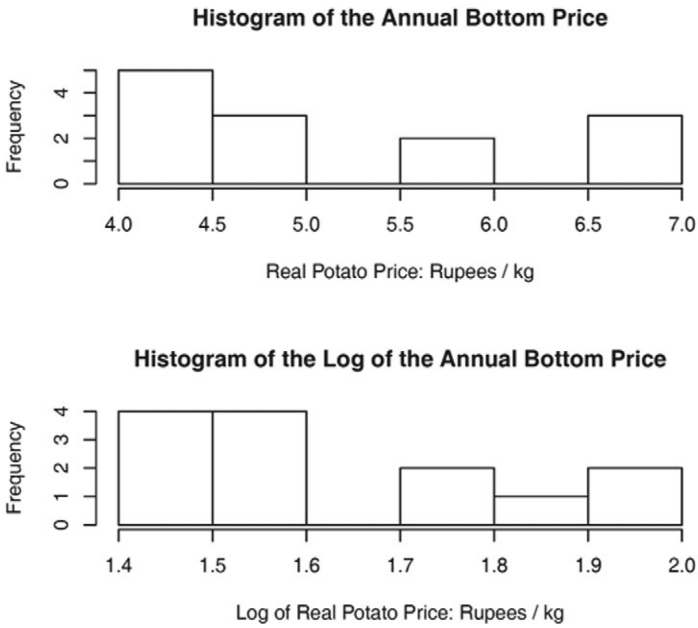

Figure 4. Annual lowest price distribution.

3. Model: Bayesian Regime-switching Specifications

We start the construction of the Bayesian model for month-ahead retail price forecasting by considering the naive model of equation (3.1),

$$y_t = \ln \frac{\mathcal{P}_t}{\mathcal{P}_{t-1}} = \ln \mathcal{P}_t - \ln \mathcal{P}_{t-1} = p_t - p_{t-1} = \alpha + \varepsilon_t. \qquad (3.1)$$

In it y_t is the change of potato retail price from price at time period $t-1$, p_{t-1}, to price at time period t, p_t. Here p_t, $t = 1, 2, 3, \ldots,$ are natural logarithms of recorded retail prices $\mathcal{P}_t$. Thus α can be simply interpreted as average growth rate for potato price and ε_t as its error in predicting the occurring price growth rate y_t in time t. It would be natural to continue by assuming that $\varepsilon_t \sim N(0, \sigma^2)$, where σ is expected to be known. Then we could also state that observed changes for log of potato price, y_1, y_2, y_3, ..., come from $N(\alpha, \sigma^2)$. We could also set a Bayesian prior for unknown average growth rate such that $\alpha \sim N(\alpha_0, \sigma_0^2)$, where α_0 and σ_0^2 are prior assumptions. Although such an approach has pedagogical virtues, the idea of having a single average growth rate is overly simplistic for the task at hand, since potato price in Delhi has seasonal and somewhat varying movements up and also violent and relatively predictable moves downwards at main harvest time. The error of the naive model would hardly be neither normal nor even i.i.d. across time.

A solution that aims at preserving pedagogical virtues of the naive model is to allow regime switches for α, varying the trend in potato retail price in time. The model for the data process that contains the regime switching of log-price change in equation (3.2) has compared to equation (3.1) now time-varying trend α_t that can be set to take into account the regime switch also for downward and upward trend change in price,

$$p_t - p_{t-1} = \alpha_t + \varepsilon_t. \tag{3.2}$$

Updating of α_t is most strongly seen in the switching of regime from crashing to rising period and vice versa where the regime changes radically but updating also happens during the price rising period. Equation (3.2) of price change may also be presented for price level in equation (3.3) where the updating of the trend and its error together with their previous occurrences and the starting price determine the current price,

$$p_t = \sum_{i=1}^{t} \alpha_i + \sum_{i=1}^{t} \varepsilon_i + p_0. \tag{3.3}$$

In equations (3.2) and (3.3) the time index is denoted t, and $\varepsilon_t \sim$

$N(0, \sigma^2)$, where σ is assumed to be known. The trend is now set to be changing for time t, so that trends α_t for each t are still unknown with prior for $\alpha_t \sim N(\alpha_{t0}, \sigma_{t0}^2)$, where α_{t0} and σ_{t0}^2 are prior assumptions for the normal distribution mean and variance parameters. We denote hereinafter corresponding data driven posterior updating or regime switch caused parameters, from which α_t will be also drawn in simulated sample paths, as α_{t1} and σ_{t1}^2. Based on data examination the trend coefficient α_t will have the prior standard deviation $\sigma_{t0} = 0.1$ for the estimated beginning month following the price tumbling. From there it starts to update following price rise, i.e. lowers towards and even below 0.05. We thus used data examination to reason the lowering of variance, roughly data of Table 1. The true $\sigma = 0.15$ is somewhat conservative. The model simulations bring slightly lower sample path errors and also reasonable posterior standard deviations for the rising period of price. The true α_t-values are assumed to be not known. Every new observation updates the distribution of the trend during price rise.

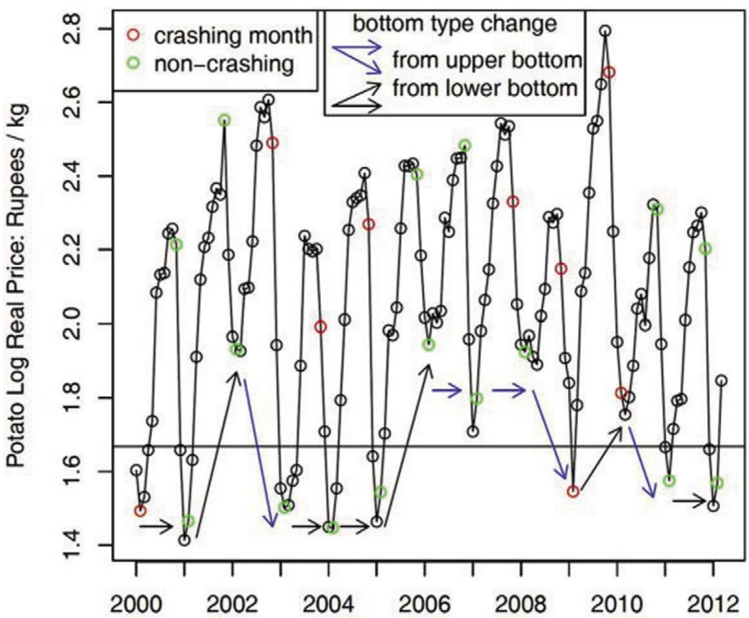

Figure 5. Logarithm of real price, January 2000 - March 2012.

Consider Figure 5. The blue and black arrows are representing cobweb oscillation of annual price bottoms around the average bottom price, which is represented by the horizontal line. The strategically important months of February and November are marked with red and green depending whether they are price crashing (change to previous month greater negative than -0.1) or not, respectively. We next present the model specification roadmap of forthcoming sections.

- Subsection 3.1 presents the derivation of normal posterior distribution updating process for the price rising period. It also illustrates the updated posterior distributions that are used to simulate a forecast sample path for the model during one year of price data.
- Subsection 3.2 presents the derivation of Beta posterior distribution updating process for four different uses of regime-switch with Bernoulli data updating the distribution.
- Subsection 3.3 builds the regime-switch concerning the strategic month of February. It is close to annual bottom prices, and is coloured in red or green in Figure 5 depending on whether it is price crashing or not. Each crashing February in data history increases the probability of February crashing for simulated forecast sample paths. Similarly each non-crashing February decreases its probability.
- Subsection 3.4 builds the regime-switch concerning the strategic month of November. It is close to annual high prices, and is coloured in red or green in Figure 5 depending on whether it is price crashing or not.
- The previous two points determine the length in months of the annual main harvest related price crash for each simulated sample path. The magnitude of the total crash for these months in log of price for each simulated sample path is determined according to the specification given in Subsection 3.5, where the annual bottom price for each sample path will be determined randomly from a normal distribution of an upper or a lower bottom. The specification for the

regime-switches between upper and lower bottoms is the subject of following two points.

- Subsection 3.6 specifies how data of lower bottom changes, presented as black arrows of the Figure 5, update the probability of lower bottom changing to upper bottom for sample paths that are used for forecasting the next bottom type change from lower bottom (change to upper bottom or remaining lower bottom).
- Subsection 3.7 specifies how data of upper bottom changes, presented as blue arrows of the Figure 5, update the probability of upper bottom changing to lower bottom for sample paths that are used for forecasting the next bottom type change from upper bottom.
- Subsection 3.8 defines how individual crashing months are behaving with respect to the total estimated crash magnitude of Subsection 3.5, that was based on two preceding points and their corresponding subsections.

Estimated parameters are presented in Table 2. In our modelling, normal distribution parameters α_{t1} and σ_{t1} of Table 2 are without memory. They belong to Bayesian updated posterior distribution that does not depend on previous year, but only on regime switches or a latest monthly price change that updates them. Contrary to this, the Beta-distribution parameters ζ, η, γ, ω, θ, κ, λ and v remember the data occurrences of previous years, meaning how many times a strategic month was rising or crashing, or how many times a specific bottom type change followed or not.

Table 2. Estimated parameters by their use as defined in corresponding subsections

		Parameter use	in distribution	Subsection
α_{t1}	σ_{t1}	Potato price growth rate	$N(\alpha_{t1}, \sigma_{t1}^2)$	3.1
ζ	η	February switch to rising	$\mathrm{Be}(\zeta, \eta)$	3.3
γ	ω	November switch to crashing	$\mathrm{Be}(\gamma, \omega)$	3.4
θ	κ	Bottom switch from lower to upper	$\mathrm{Be}(\theta, \kappa)$	3.6
λ	v	Bottom switch from upper to lower	$\mathrm{Be}(\lambda, v)$	3.7

3.1. Normal prior and posterior distribution with data coming from normal distribution

The updating into the posterior distribution of α_t of equations (3.2) and (3.3) is established here. It concerns the potato price growth rate at time *t*, using in derivation of its distribution previous data occurrence (i.e. y_{t-1}) and the previous posterior mean (i.e. the one of α_{t-1}) as prior mean α_{t0}. There are exceptions when we will not be using previous data occurrence or not setting previous posterior as new prior as such. These are main harvest price crashing period and minor harvest related months June and August.

The normal function has density

$$f(y \mid \mu, \sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{1}{2\sigma^2}(y-\mu)^2\right).$$

Following Bayes theorem we have that Posterior $\propto$ Likelihood $\times$ Prior. Posterior is therefore calculated from

$$\prod_{i=1}^{n} \exp\left(-\frac{(y_i-\mu)^2}{2\sigma^2}\right) \times \exp\left(-\frac{1}{2\sigma_0^2}(\mu-\mu_0)^2\right)$$

which is also a normally distributed $\mu \sim N(\nu, \delta^2)$, where

$$\nu = \left(\frac{\mu_0}{\sigma_0^2} + \sum_{i=1}^{n} y_i / \sigma^2\right)\delta^2$$

and where $\delta^2 = \sigma_0^2\sigma^2/(\sigma^2 + n\sigma_0^2)$.

When $n = 1$, i.e. when posterior updating happens from one observation as in this research, the posterior distribution parameters still simplify to $\nu = \frac{\sigma^2\mu_0 + \sigma_0^2 y_1}{\sigma^2 + \sigma_0^2}$ and $\delta^2 = \frac{\sigma^2\sigma_0^2}{\sigma^2 + \sigma_0^2}$, as in [9, p. 40].

In this research, the data y_i is the growth rate $p_i - p_{i-1}$, $i = 1, 2, ..., n$ which is the actual monthly change in potato price and it follows $N(\alpha_t, \sigma^2)$

i.i.d., where σ^2 is assumed to be known. The time-varying trend coefficient α_t that represents the trend μ in this research is assumed to be unknown and has a prior $N(\alpha_{t0}, \sigma_{t0}^2)$. Thus time-varying α_{t0} and σ_{t0} are representing the prior parameters μ_0 and σ_0 of above presentation, respectively.

The prior for growth rate in the beginning of every rising trend of price is $\alpha_t \sim N(\alpha_{t0}, \sigma_{t0}^2)$ and the starting values are $\alpha_{t0} = 0.05, \sigma_{t0} = 0.1$ based on the Bayesian belief. The annual rising price trend may begin in either February or March. Looking from Figure 3 the expected growth rate for non-crashing February instances and the three instances of March, where February still crashed, is about 0.05. Since the potato price growth rate is quite varying, not only between years but also month by month, the model uses only one earlier observation to update the trend direction. Seeking a common trend from the low price until the high price would make the posterior updating far too slow as the powerful rise of June starts. Also slowing down of the price rise in August should be quickly updated, but it cannot happen if the recalculated posterior distribution is affected by occurrences several months back. In that case the estimated values would be destined only above the actual growth rate values. Because of these points of view the model has for June and August its own posteriors with distribution of α_t independent of past data. A kind of regime switching is thereby happening also for these months although it is not as radical as the main harvest related regime switches. Incidentally these months closely coincide with Indian subcontinent minor harvests.

The distribution for α_t for the estimated month following crashing stop, February or March, comes from $N(0.05, 0.1^2)$. Thereafter the posterior will be updated by the data so that $\alpha_t \sim N(\alpha_{t1}, \sigma_{t1}^2)$ similarly as $\mu \sim N(\nu, \delta^2)$ above. In practice for this model α_{t1} is the weighted mean of prevailing α_{t0} and the latest actual price change, weighted by inverses of σ_0^2 and σ^2, respectively. Standard deviation on the other hand will get lower irrespective of price growth rate changes as the posterior is being updated until it will be returned to 0.10 for the first crashing month of the main harvest, either November or December, according to regime switching.

A typical posterior updating or regime switch caused distribution example for the growth rate $\alpha_t \sim N(\alpha_{t1}, \sigma_{t1}^2)$ is illustrated in Table 3 that follows one possible sample path for α_t as the year 2004 data is updating the distribution. This sample path erred in its regime switches expecting a prolonged crash until February 2004 upper bottom, and erred again at expecting the November 2004 not yet crashing but was correct that February 2005 would no more crash as lower bottom would have been reached. With a thousand simulated sample paths for price change each path is representing 0.1%. If the model is true, a diverging sample path can be interpreted as a rare but possible event that could happen. Table 3 is also presented graphically in Figure 6.

Table 3. A sample path posterior distribution parameter realizations for drawing α_t

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
α_{t1}	-0.06	0.05	0.07	0.11	0.19	0.20	0.069	0.06	0.056	0.056	-0.55	-0.37
σ_{t1}	0.10	0.10	0.08	0.073	0.065	0.06	0.056	0.052	0.049	0.047	0.10	0.10

Compared to earlier data pre-examination and monthly standard deviations in Section 2 a similarity that is accomplished by the model is that the model standard deviation will fall from 0.1 to 0.05 from March to October and is returned to 0.1 as crashing starts, often in November as seen from its negative mean for growth rate in Table 1.

Considering the example sample path distributions it is worth noticing that in this sample path the regime will be switched to crash in December and the regime of price rise starts in March. It can be also seen how the months of June and August change the mean of the posterior distribution. The year in question 2004 has a strong rise in April, about 25% that affects the May posterior and therefore for this single year separate June posterior would not be needed. On many other years, however, it is necessary if we wish to take into account the June price rise as the May data is often witnessing only little change to price. We install a mean of 0.19 for June in place of posterior mean that followed from Bayesian updating effected by May price change.

The necessary stopping of price rise in August is effected by the smaller regime switch with the mean of α_t equalling 0.069 installed in place of posterior mean that resulted from Bayesian updating from July price change. The main harvest related regime switches of this sample path cause the tumbling of price to be divided between November, December and 2005 January, with the December α_t mean being 60% of the full estimated price fall. These regime switch related changes, compared to allowing ordinary Bayesian updating, are based on data means in Table 1.

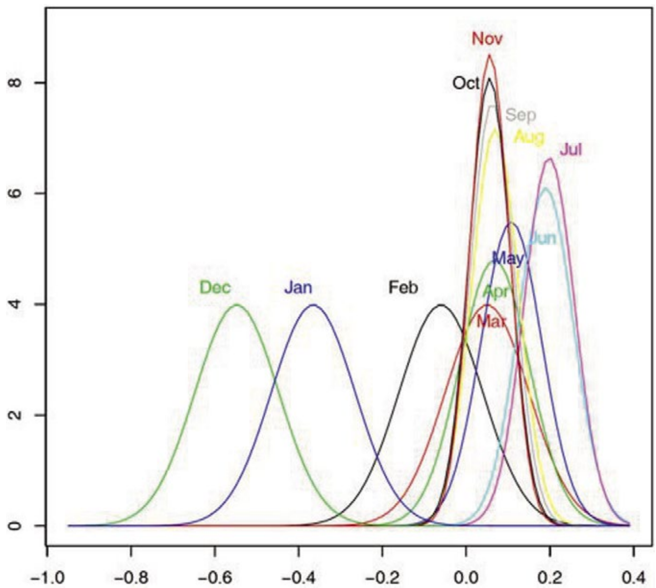

Figure 6. Bayesian learning: distributions from which α_t is drawn for each month in a sample path with prior and data information from 2004 updating them.

3.2. Beta prior and posterior distribution with data coming from Bernoulli distribution

In the beginning of main harvest tumbling the model selects either a lower or an upper bottom distribution with means 1.5 and 1.85, respectively. The probability is dependent on the previous year bottoming price and is being updated by the actual occurrences. Similarly coin flipping between two options happens also when selecting the month of price crash starting and the month of price crash ending.

In such choices between two we can use the following model where the i.i.d. data comes from Bernoulli distribution $x_1, x_2, ..., x_n \sim Ber(p)$, and the prior before the first observation is $p \sim Be(\iota, \phi)$.

According to Bayes theorem Posterior $\propto$ Likelihood $\times$ Prior. We receive

$$\prod_{i=1}^{n} p^{x_i}(1-p)^{1-x_i} \times p^{\iota-1}(1-p)^{\phi-1} = p^{\iota+\sum x_i-1}(1-p)^{\phi+n-\sum x_i-1}$$

i.e. the posterior distribution is $Be\left(\iota + \sum x_i, \phi + n - \sum x_i\right)$.

In this research, the original prior for Beta before the first observation is in all applied situations $Be(1, 1)$ so $\iota = \phi = 1$. $Be(1, 1)$ equals $Uniform(0, 1)$, which is uniform distribution between 0 and 1. This is a situation where both two of the data occurrences are possible but this is all that is known about the data process before the first occurrence.

We use a Markov chain like process where the current state affects the next state with some probability. The difference to ordinary Markov chain is that in this research the probabilities are being updated by the Bayesian learning process and thus are not constant. The possible states are upper or lower bottom and crashing or not of strategic months of November and February. See Figure 5 black and blue arrows for bottom type changes.

Consider first the case where accruing data is presented as black arrows in Figure 5. In the beginning we sample the path estimates with their probability dependent on the $Be(1, 1)$ distribution that is same as the uniform distribution. As data is accruing the Beta distribution is being transformed. The year 2000 start lower bottom is followed by the year 2001 lower bottom.

This makes the ‘lower bottom to lower bottom’ probability distribution change and thus $Be(1, 1)$ will be transformed to $Be(2, 1)$. The next year brings the first upper bottom so the ‘lower bottom to lower bottom’ related posterior will be again updated, now to $Be(2, 2)$. Now as the chain has come to visit the upper bottom, the estimated probability for moving from upper bottom to either upper or lower bottom is still 0.5 for both because only the next move will need and update that probability. Similarly in the second case the blue arrows update the probability of ‘upper bottom to lower bottom’.

The third case is that Bayesian learning through the Beta distribution is applied to the possible states of crash starting in either November or December. In the beginning the sample estimate distribution is $Be(1, 1)$ causing dependence on the probability of choosing either November or December as crash start. The updating of the Beta distribution will occur according to crash start months occurring in past data. The fourth case for similar use of Beta distribution is the updating through Bayesian learning whether the price crash will end in January or February. The limit for price crash was defined as -0.1 logarithmic monthly price change.

The following subsections present how the model takes into account the regime switch in either January or February as the price begins to rise. Correspondingly the regime switch as price starts to tumble in either November or December is presented. The bottoming of the annual crash in potato price comes from two distributions. The selection between the two is made by the previous bottom, the previous bottom being defined lower bottom if the price gets below 5.30 rupees in our real price data. Otherwise the previous bottom is an upper bottom. After thereby defining for every sample path both the ending price and starting price for the estimated crashing period the coefficient α_{t1} for the price crashing distribution for every month can be directly calculated. Drawn from $N(\alpha_{t1}, 0.1^2)$, α_t will then be inserted into equation (3.2) as an estimate for the change in potato price for every simulated sample path of the model.

Recall that the trend coefficient α_t in equations (3.2) and (3.3) has its drawing distribution updated by the process of Bayesian learning during the price rising period. The specification for its posterior distribution formation was presented in Subsection 3.1 as derived from the density function of the normal distribution and from the prior distribution, that was given a starting guess based on the expected value for the price change of the beginning month of rising price period in the data. An example of the posterior updating for the rising period of potato price was also provided for a single sample path. The regime switches related to change between rising and crashing price periods use the Bayesian updating as above, deriving posterior distribution based on Beta distribution that is used in the model for four separate purposes. The defining of its four uses as well as the calculation of the main harvest related price tumbling and its monthly estimate follows next in Subsections 3.3, 3.4, 3.5, 3.6, 3.7 and 3.8.

3.3. The month of price regime switch from tumbling to rising

The potato price regime switch from the downward or crashing trend into the upward trend has been coded in the following way. The crashing of price means that the change in price compared to the previous month price is smaller than -0.1 in logarithmic scale. In the regime switch the first month of rising price the drawing distribution is set to $\alpha_t \sim N(0.05,\ 0.1^2)$.

The model gets from the distribution $Be(\zeta,\ \eta)$ the probability of January being the last crashing month. If regime switch does not occur in a sample path following January it will occur at the latest after February. In the beginning before any actual data price crashes have ended it is defined that $\zeta = 1$ and $\eta = 1$. Every occurrence in the data history of February still crashing increases ζ by one. Similarly if February no longer crashed in a year but crashing ended in January the η value will be increased by one for all past data crash ending history that has occurred so far.

The Beta-distribution parameters receive values from the past data history and contribute to sampling in the following manner:

$\zeta = 1 +$ number of earlier February months that did not crash,

$\eta = 1 +$ number of earlier February months that did crash,

$X \sim Be(\zeta, \eta)$, $Y \sim Uniform(0, 1)$, where x is a realized observation of the random variable X and y is a realized observation of the random variable Y. If $x > y$, then the regime will be switched in the sample path already after January that is February no longer crashes in the estimate of the sample path. If $x \le y$, then the regime will be switched only after February.

3.4. The month of price regime switch from rising to tumbling

The potato price regime switch from the upward trend into the downward or crashing trend has been coded in the following way. The crashing of price again means that the change in price compared to the previous month price is smaller than -0.1 in logarithmic scale.

The model gets from the distribution $Be(\gamma, \omega)$ the probability of after every October switching into the downward or crashing trend for November. If regime switch does not occur in a sample path following October it will occur at the latest after November so that December always crashes. In the beginning before any actual data occurrences of tumbling in the price $\gamma = 1$ and $\omega = 1$. Every occurrence in the data history of November already crashing increases γ by one. Similarly if November did not crash in a year but crashing started in December the ω value will be increased by one for all past data crash start history that has occurred so far.

The Beta-distribution parameters receive values from the past data history and contribute to sampling in the following manner:

$\gamma = 1 +$ number of earlier November months that did crash,

$\omega = 1 +$ number of earlier November months that did not crash,

$X \sim Be(\gamma, \omega)$, $Y \sim Uniform(0, 1)$, where x is a realized observation of the random variable X and y is a realized observation of the random variable Y. If $x > y$, then the regime will be switched in the sample path already after October so that November will crash in the estimate of the sample path. If

$x \leq y$, then the regime will be switched only after November so that crash will start in December.

3.5. On calculating the trend coefficient of the tumbling price months

By the time the start of the price crashing due to main harvest season approaches the estimated length in months of the crash for a sample path is known from Subsection 3.3 and 3.4 definitions. What is still needed for the model is the estimate of the bottom price that will happen during the last crashing month for a sample path. Studying the data with the help of the cobweb theory, it was observed that the bottom price of the crashing would come from two distributions of logarithm scale either from $N(1.5, 0.05^2)$ or from $N(1.85, 0.1^2)$. It was also reasoned that the probability between upper and lower bottom for the current bottom could be determined by the last year's bottom price. The qualifying limit of the previous bottom price into upper or lower bottom is by the real potato price of 5.30 rupees that is in the logarithmic scale 1.67.

In the spirit of the first order Markov chain [1, pp. 117-120] if the previous bottom from which the trending up has been occurring was a lower bottom then by some known probability the crashing ahead will end in a lower bottom. Another option would be an upper bottom if the lower bottom will not be drawn from the Beta distribution for a sample path. Correspondingly if the previous bottom was an upper bottom then by some known probability the crashing will end in an upper bottom. And again there is only one option that is the lower bottom. The difference compared to the ordinary Markov chain is that due to the Bayesian learning process the above mentioned known probabilities are being updated as observations are accruing.

Let us define π_{ll} = the probability that the lower bottom is followed by the lower bottom, and π_{ul} = the probability that the upper bottom is followed by the lower bottom. Correspondingly $1 - \pi_{ll}$ = probability that the lower bottom is followed by the upper bottom, and $1 - \pi_{ul}$ = probability that the upper bottom is followed by the upper bottom. The Markov chain transition matrix representing these probabilities:

$$\Pi = \begin{bmatrix} \pi_{ll} & 1 - \pi_{ll} \\ \pi_{ul} & 1 - \pi_{ul} \end{bmatrix}.$$

In the model in question the probabilities are not constant contrary to ordinary Markov chain but they will be drawn from Beta distribution such that $\pi_{ll} \sim Be(\theta, \kappa)$ and $\pi_{ul} \sim Be(\lambda, v)$ and the shape of the distributions will be updating following Bayesian learning process according to the Subsections 3.6 and 3.7.

3.6. The previous year real bottom price being below 5.3 rupees

If the previous bottom was a lower bottom the model receives from the $Be(\theta, \kappa)$ distribution the probability that the next crashing bottom will be from a lower bottom distribution. The option for a sample path is an upper bottom. In the beginning before any earlier observations that is without the first observed new bottom that would have followed a previous lower bottom $\theta = 1$ and $\kappa = 1.$ Every occurrence in data history of a lower bottom that followed the previous lower bottom increases θ value by one. Correspondingly every upper bottom that followed the previous lower bottom increases κ value by one.

The Beta-distribution parameters receive values from the past data history and contribute to sampling in the following manner:

$\theta = 1 +$ number of earlier true occurrences of lower bottom following the previous lower bottom where lower bottom is defined as real price crashing below 5.30 rupees,

$\kappa = 1 +$ number of earlier true occurrences of upper bottom following the previous lower bottom, upper bottom is defined as real price not crashing below 5.30 rupees,

$X \sim Be(\theta, \kappa),\ Y \sim Uniform(0, 1),$ where x is a realized observation of the random variable X and y is a realized observation of the random variable Y. If $x > y,$ then the model sample path will be followed by a lower bottom that is the bottom will come from the distribution $N(1.5, 0.05^2)$. If $x \leq y$, then the sample path will get its next crashing bottom estimate from the distribution $N(1.85, 0.1^2)$.

3.7. The previous year real bottom price being at least 5.3 rupees

If the previous bottom was an upper bottom the model receives from the $Be(\lambda, v)$ distribution the probability that the next crashing bottom will be from a lower bottom distribution. The option for a sample path is an upper bottom. In the beginning before any earlier observations that is without the first observed new bottom that would have followed a previous upper bottom $\lambda = 1$ and $v = 1$. Every occurrence in data history of a lower bottom that followed the previous upper bottom increases λ value by one. Correspondingly every upper bottom that followed the previous upper bottom increases v value by one.

The Beta-distribution parameters receive values from the past data history and contribute to sampling in the following manner:

$\lambda = 1 +$ number of earlier true occurrences of lower bottom following the previous upper bottom,

$v = 1 +$ number of earlier true occurrences of upper bottom following the previous upper bottom,

$X \sim Be(\lambda, v)$, $Y \sim Uniform(0, 1)$, where x is a realized observation of the random variable X and y is a realized observation of the random variable Y. If $x > y$, then the model sample path will be followed by a lower bottom that is the bottom will come from the distribution $N(1.5, 0.05^2)$. If $x \leq y$, then the sample path will get its next crashing bottom estimate from the distribution $N(1.85, 0.1^2)$.

3.8. Calculating the monthly magnitude of the main harvest related price tumbling

The Subsections 3.3 and 3.4 defined how the months of annual main harvest related price crashing start and price crashing end are randomly selected for a sample path. Also it was defined in Subsections 3.5, 3.6 and 3.7 how the bottom price will be estimated. When calculating the monthly magnitude of the price tumbling it will be furthermore taken into account that the December takes 60% of the full price descend. It is also coded in the model that the starting price of tumbling will be the greater of the two latest price observations before the estimated sample path crashing moment so that November crashes would not dilute the December as the main crashing month.

Now with the knowledge of the starting and ending price of the crash the expected magnitude of full price crash in a sample path is calculated as in equations (3.4), (3.5) and (3.6),

$$TotalCrash = StartingPrice - EndingPrice. \tag{3.4}$$

December crash is:

$$DecemberCrash = TotalCrash \times 0.6. \tag{3.5}$$

The crash for other crashing months is:

$$OtherCrash = \frac{TotalCrash \times 0.4}{OtherMonths}, \tag{3.6}$$

where *OtherMonths* is the estimated number of crashing months without December. It is dependent on sample path estimated crashing start and ending months. Other crashing months have their α_t following the distribution $N(OtherCrash,\ 0.1^2)$ and December crash is following the distribution $N(DecemberCrash,\ 0.1^2)$.

4. Results: Model Parameter Evolutions, Month-ahead Forecast Prices and Forecasting Error

The model, as set in earlier Section 3, has sample paths that are simulated for 12 years of data and compared with the actual data. From these many estimated paths of 12 years the median estimate and quartile limits are calculated. These can be also compared to the actual price behaviour.

The results first present posterior Beta distributions received through Bayesian learning as more data is added. This presentation is applicable due to relatively small number of Beta posteriors. Another Bayesian learning object in the model is the potato price growth rate α_t, which is normally distributed. Depending on the estimated annual crash start and ending months, however, sample paths receive different normal growth rate distributions, especially the growth rate α_t may be markedly different for the possible crashing months. For this reason after studying Beta distribution we will move to study the graphs of sample paths of the model. By using the generated 1000 pseudorandom number sample paths median we get a visual picture for the updating of α_t through the previous month data during rising period but also we will see the median sample path estimate for crashing months. This is applicable also for both June and August months, during which the previous month change in the growth rate does not directly affect the posterior distribution. These June and August realizations of the data are related to minor harvests and any divergence from common expectations in harvest supply or timing may affect the near months' price growth rates. These two minor harvests are taken into account in this research through pre-examination of data for June and August growth rates.

4.1. Evolution of the posterior probability distribution of the month of rising start

Figure 7 presents how the probability for the price crash to end already in January instead of February is drawn from the updating Beta distribution. The initial distribution $Be(1, 1)$ is equal to the uniform distribution. The year 2000 February was still a crashing month so the Beta distribution was updated to prefer February and the posterior distribution for January being the last crashing month was updated to be $Be(1, 2)$ in the figure. When thereafter followed 8 years in row when February did not crash any more after January crashing, $Be(9, 2)$ eventually became the posterior distribution of the crash ending in January. Years 2009 and 2010 February was crashing, however, after which $Be(9, 4)$ was the sampling distribution for year 2011.

4.2. Evolution of the posterior probability distribution of the month of crashing start

Figure 8 shows how after two December start crashes the probability distribution mass for November crashing moves first to the left. But after more November crashes happen in the following years, the 2012 end probability for the November and the December crashing starts are equally likely.

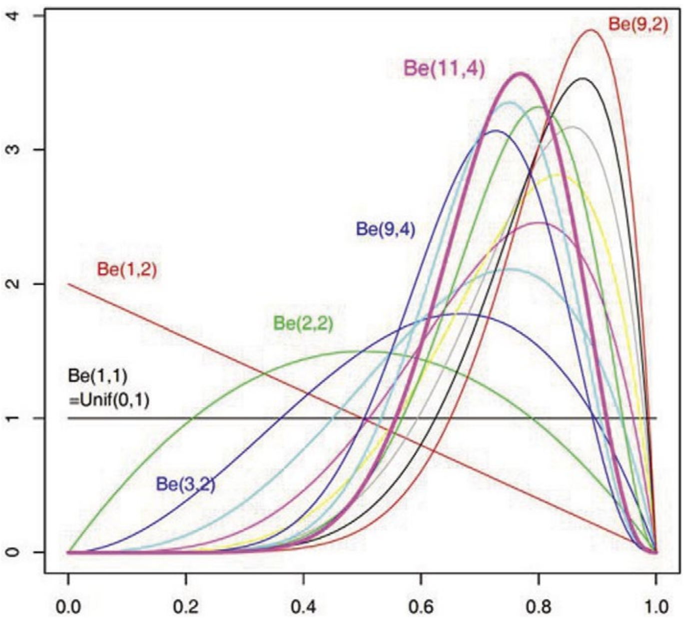

Figure 7. Bayesian learning affects the probability February does not crash.

4.3. Evolution of the posterior probability distribution of the bottom following lower bottom

Figure 9 presents how $Be(1, 1)$ prior was transformed into $Be(2, 1)$ when the beginning of year 2000 lower bottom was followed by the beginning of year 2001 lower bottom. Still lower bottoms were later on followed by upper bottoms as well. The most likely outcome for the 2013 bottom is a lower bottom i.e. coming from distribution $N(1.5, 0.05^2)$. The probability for this lower bottom occurring instead of an upper bottom will be drawn from the distribution $Be(5, 4)$, meaning that upper bottom with distribution $N(1.85, 0.1^2)$ is almost as likely.

4.4. Evolution of the posterior probability distribution of the bottom following upper bottom

Figure 10 presents the posterior updating for the probability that an upper bottom is followed by a lower bottom. The first upper bottom at the start of 2002 was followed by a lower bottom in year 2003. This caused the posterior distribution to take the shape of $Be(2, 1)$. However, the next occurrence of an upper bottom at the start of 2006 was followed by an upper bottom, even twice before the lower bottom occurred at the start of the year 2009. The start of the year 2010 upper bottom was followed by a lower bottom updating the posterior into its latest shape to $Be(4, 3)$. A next upper bottom occurring will then lead to prediction, based on $Be(4, 3)$ distribution, for the choice between lower or upper bottom for the sample paths.

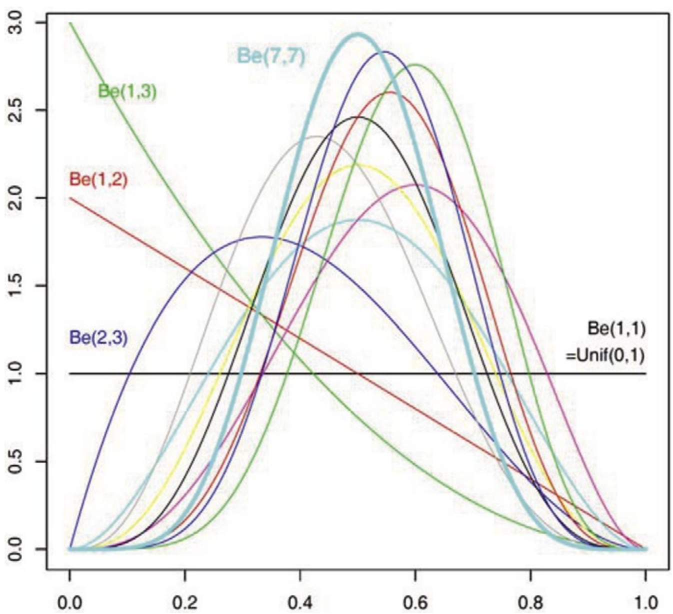

Figure 8. Bayesian learning affects the probability for November already crashing.

4.5. Sample paths generated by the model and their median

Using equations (3.2) and (3.3) we can simulate one-month-ahead forecast sample paths for potato price with α_t being a simulated pseudo-random realization from $N(\alpha_{t1}, \sigma_{t1}^2)$. During price rising periods α_{t1} and σ_{t1}^2 depend on Bayesian posterior updating, that is based on latest occurred price change and prior distribution before latest price change (see Subsection 3.1 and Table 3 example). Specifications of Subsections 3.2, 3.3, 3.4, 3.5, 3.6, 3.7 and 3.8 dictate the parameters of $N(\alpha_{t1}, \sigma_{t1}^2)$ when the regime is switched to price crashing instead. Adding a simulated realization α_t, which comes from above regime switch specifications for each sample path, to latest occurred price p_{t-1} gives a sample path forecast price for time *t*. This forecast price can be compared to next occurring price p_t. We will be also studying the forecast error, which is one-period-ahead forecast for time *t* subtracted from the occurring price at time *t*.

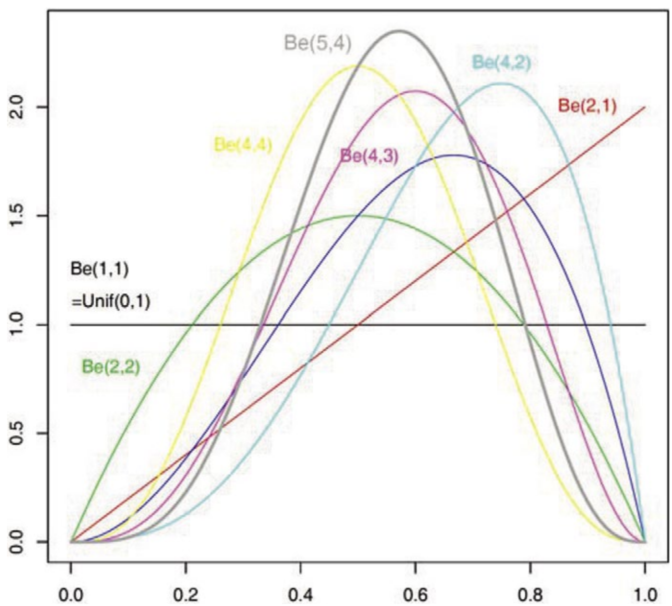

Figure 9. Bayesian learning affects the probability for lower bottom being followed by a lower bottom.

Figure 11 has pictured all 1000 simulated coloured sample paths of the model and the real price that occurred is in black. Figure 12 presents aside occurred prices the median and the 1st and 3rd quartiles of the sample paths which may give a clearer picture how the model is working.

In Figure 12, we note that the red line or the median of randomly simulated 1000 sample paths is in practice caused by the mean of α_t presented in equations (3.2) and (3.3) and represents most likely forecast of the model. First of all we notice comparing price to median estimate that the model we built has a very desirable property. Its predictions for price growth rate are not visibly biased downwards or upwards compared to occurring data in usual trending phases.

Distribution mean updating for August independent of past data seems reasonably decent solution. The predictions for the year ends give quite realistic guesses for the potato price, where it somewhat fails, however, is guessing year 2001 November strong spike in price. The predicted sample paths' third quartile could be closer to the realized value if the model would not still at this stage implicate very strongly that the next bottom will be drawn from the lower bottom because the previous lower bottom was followed by a lower bottom. Still some of the simulated 1000 sample paths do hit close to the 2001 November realized price. A greater problem for the model realism is that the generally strong rise in June is not necessarily followed by a strong July rise. On the contrary it seems that greater the price rise in June, smaller it will be in July. This explains why none of the 1000 sample paths did pass below the year 2006 July value which surprising the model even fell after a 30% rise of price in June. Still a single sample path could have hit the July 2006 value although -4σ away from the mean. One correcting possibility would be to allow the July standard deviation of α_t to be closer to that of the data. Still it might be better to take into consideration that July price rise strength is inversely dependent on June price rise strength. Coding such nuances has not been implemented in the current model, and they also lack full support from Figure 3 since half of the occurring price changes for July are packed narrowly and in three of the other cases July is increasing price even stronger than June.

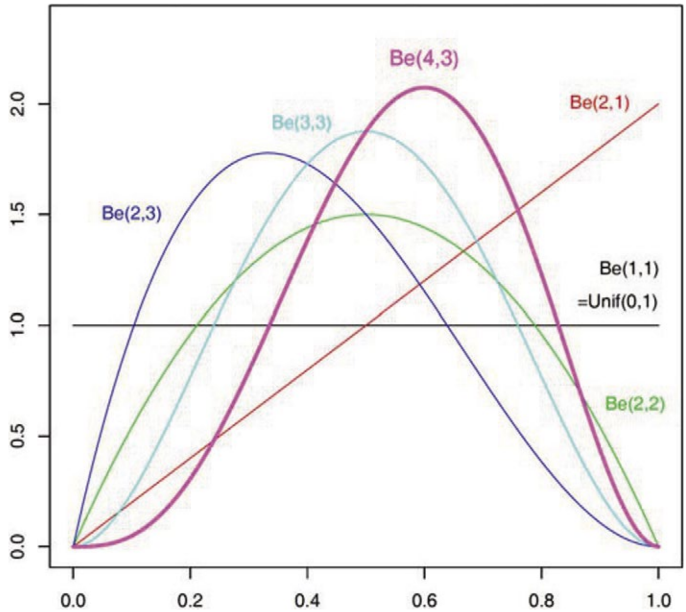

Figure 10. Bayesian learning affects the probability for upper bottom being followed by a lower bottom.

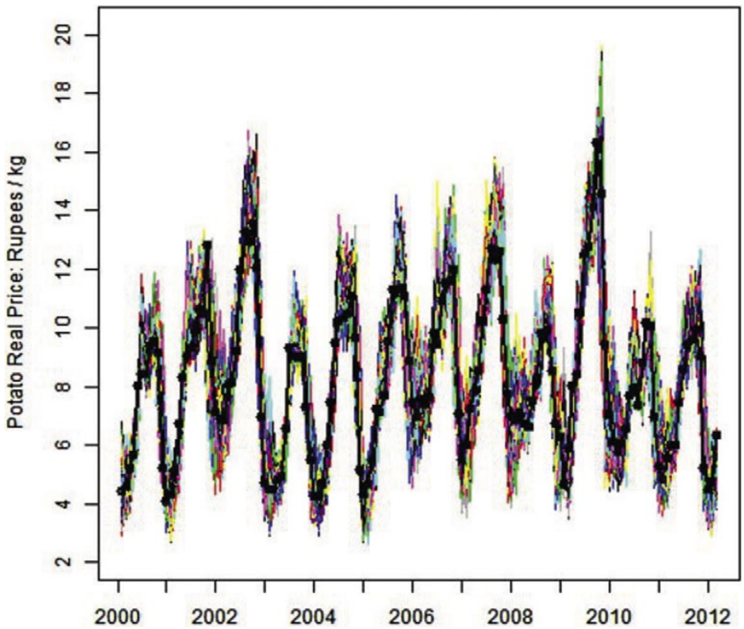

Figure 11. 1000 estimated sample paths for 2000-2012.

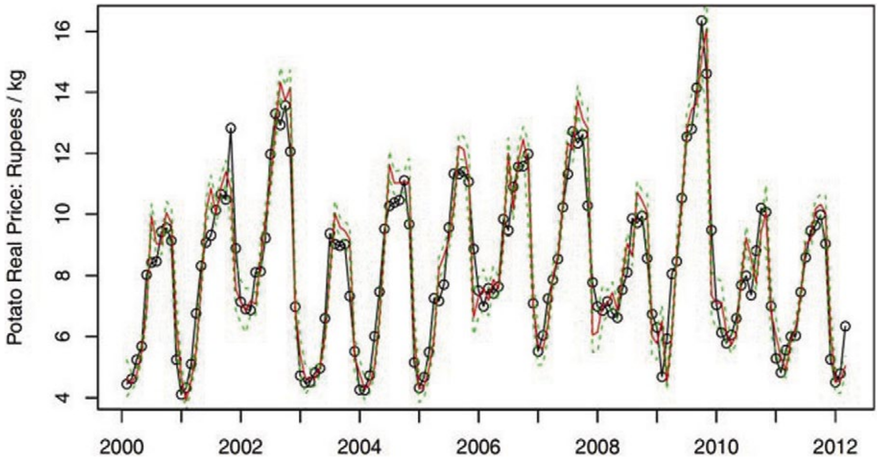

Figure 12. Potato price with model sample path median, 1st and 3rd quartiles.

Year 2009 February crashing is even greater than the previous December giving an exception to the 60% rule for December share in crashing. To add, by the start of 2009 the model has just learned that January is with great probability the last crashing month, following Figure 7. The model gives a median prediction of rising price for February. February is then crashing by 30%; the median prediction error is of course great. Thus, straight after in March 2009 this model that had a great part of its sample paths expecting the price rise to have started already in February is updating the posterior predictions for the sample paths through the strong negative price change, giving the expectation for the price fall in March. The price then rose strongly in March 2009; we have a relatively big median prediction error to other direction.

In Section 3, we assumed standard deviation of the ε_t to be known. We will next evaluate simulation forecasting error, both for median prediction and a single sample path (the last one of one thousand). Supplementary Appendix Figures S4 and S5 present median sample path error and a sample path error. Median error mean is -0.004 and standard deviation is 0.111, whereas a sample path prediction error mean is -0.009 and standard deviation is 0.135. Although the Appendix Figures S4 and S5 seem to indicate that ε_t

is randomly distributed, we still inspect their corresponding autocorrelation functions (ACF). Appendix Figure S6 presents the ACF for error median for all 1000 sample paths. It looks like white noise since dependency vanishes already on the first lag. [3, p. 478] recommends checking the ACF of squared values of suspected random variables similarly, since squares of random variables are independent if the originals are. In Appendix Figure S7, we notice that first lag is somewhat above confidence line, so it is possible that there is some dependency left in the median error. Similarly we check the ACF for a sample path error in Appendix Figure S8 and a sample path squared error in Appendix Figure S9. Both show vanishing ACF for all lags, so we conclude that error is white noise.

5. Summary Discussion

We conclude by summary discussion of the Bayesian regime-switching model and its retail price forecasting ability. At the onset of modelling work, the Delhi potato price seems simpler in its behaviour than it actually is. The intuitively appealing idea of choosing a prior for potato price rising trend and allowing its annual strengthening by learning after incoming data observations turns out problematic. The potato price behaviour does not follow a common trend, but is strongly rising in June-July and generally rising slowly or even slowly falling before the main harvest caused crash. A much stronger and sensible to changes trend updating is therefore needed. In the model implemented, we have separately installed distribution means for June and August that do not depend on previous month price change. In addition, it was natural to take into account the detail from pre-examining the data that the December crash has expected value of 60% of the annual crash.

The modelling was implemented through monthly changes where the growth rate has after the crashing end a normal prior distribution $N(0.05, 0.10^2)$ that will be updated to a normal posterior distribution through Bayesian data learning. However, only the previous month data was allowed to affect the learning process in order to implement reasonably fast changes in posterior so that predictions would not be hopelessly erroneous downwards in summer months and similarly upwards at year end. Thus excepting minor harvest related June and August, and main harvest related price crashing months, the previous month updated posterior distribution became the prior distribution for the following month. In the rising period, it was thus based on data examination taken into account that the June rise is always greatest and that after August the rise will always get slower. A simple solution was to give these specific months a distribution mean that was independent of the past data. The solution seems reasonably successful in regard to model predictions generally but the June-July movements in price might benefit from a more complicated solution as the implemented model has difficulties to take into account the sharp July price drop that occurred in 2006.

Regime switch from rising to falling was implemented either in November or December for sample paths. The expected bottoming price and the month of bottoming for sample paths were randomly drawn. December was weighted to be the greatest crash month according to the data. A regime was set from rising to falling either following January or February, when growth rate prior was reset to its initial value.

Beta distribution is used in the model for separated instances of Bayesian updating with data coming from Bernoulli distribution. Its use cases are the choice between crashing start in November or December and similarly crashing end in January or February, like also the decision if the next bottom will be drawn from an upper bottom $N(1.85, 0.1^2)$ or from a lower bottom $N(1.5, 0.05^2)$ into which the data seemed to divided by visual inspection following the cobweb theory. In the last mentioned decision process the model uses knowledge similarly to Markov chain whether the previous lower bottom was followed by a lower bottom or an upper bottom. A similar Markov like chain exists also for choosing if an upper bottom is followed by an upper bottom or a lower bottom. Similarly as for first degree Markov chains generally, where only the very previous occurrence affects the next decision, in this model also the principle is the same. The addition compared to Markov chain is that the probabilities related to the Beta distribution that affect the switch between the states are being updated through the process of Bayesian learning and are therefore not constant and are also indirectly dependent on all previous states.

The data affected notable changes to the January bottom prediction density. As the first observation counted as crashing price bottom happened in February 2000, the likelihood for February crashing bottom occurring in 2001 increased. However, eight consecutive years followed when the crashing of price ended already in January, and in the end of our data January is much more likely as last crashing month than February.

In general, it would be possible to make the model even more Bayesian. The bottom price distribution could be updated trough Bayesian learning whereas it is now implemented as two unchanging normal distributions with the hindsight of all our data. We fixed the logarithm change -0.1 as a limit for crashing month, which simplified the model. A possible extension of the model would be to remove this constraint and to allow also this limit to be updated by Bayesian learning of the data. Then other months could also be allowed as crashing months. The updating of probabilities related to start and end months of crashing would then need to be implemented through multinomial Dirichlet distribution [9, pp. 35, 167], the generalization of Beta distribution used in this study. For higher frequency modelling or other markets such generalizations are likely to bring added modelling benefit.

It is according to the data quite sensible to use normal densities for monthly price changes with true error standard deviation. More calculation would have been required with both growth rate and error standard deviation unknown, when the updated posterior distribution could have been estimated by Gibbs sampling [1, p. 122]. In it inverted variance could come from Gamma distribution allowing a more flexible consideration for the error standard deviation compared to our more rigid solution where we saw posterior standard deviation of price growth rate change from 0.1 to 0.05 updated by our data during price climbing. Such an alternative solution would specifically allow to take into account study cases where the years may be very varying by their growth rate standard deviations. Our chosen and implemented solution reasonably fitted into presented monthly data framework, and its forecasting error seems independent of price regimes and trend direction.

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Supplementary Appendix: Potato Price Forecasts in Delhi Retail from Bayesian Regime Switching

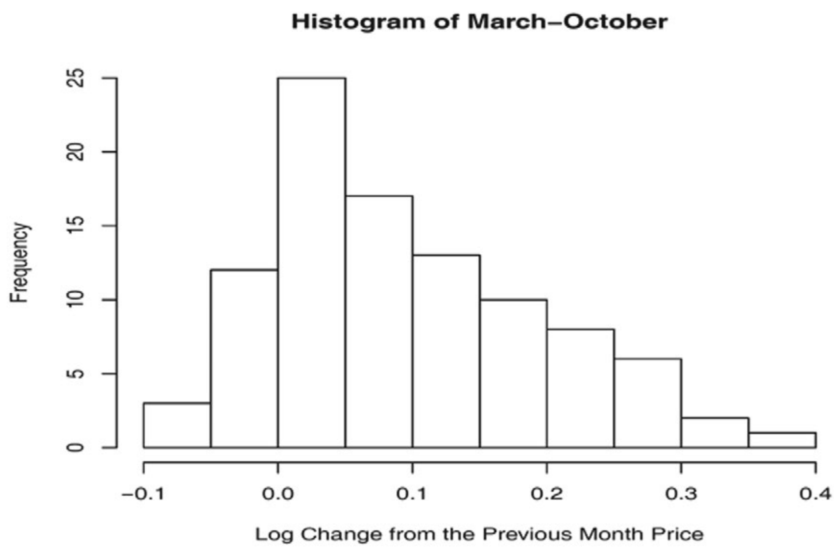

Figure S1. Histogram for usual price rising months, with all months together.

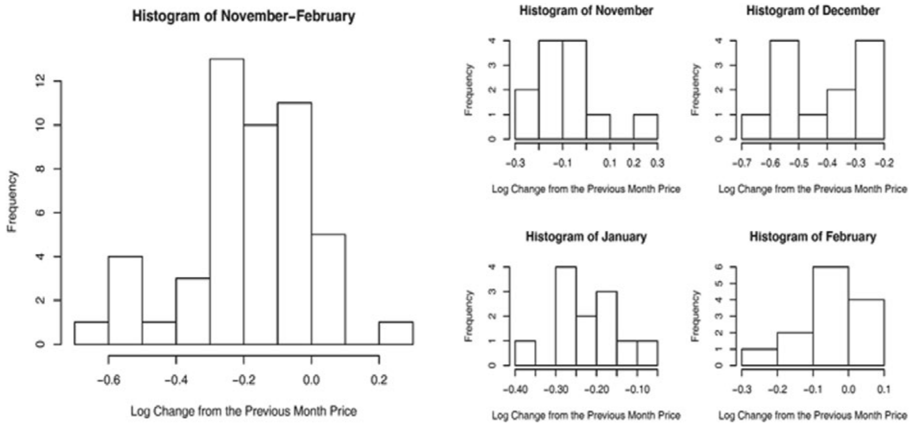

Figure S2. Histograms for usual price crashing months, first all together, then separately by month.

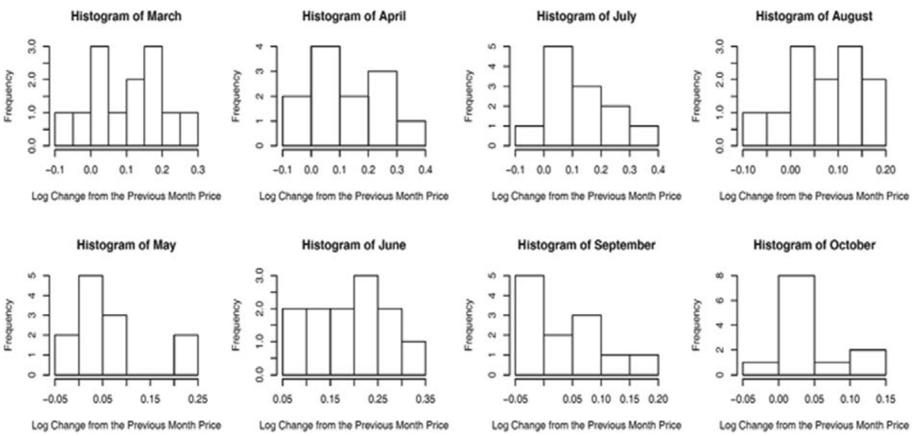

Figure S3. Histograms for usual price rising months, separately by month.

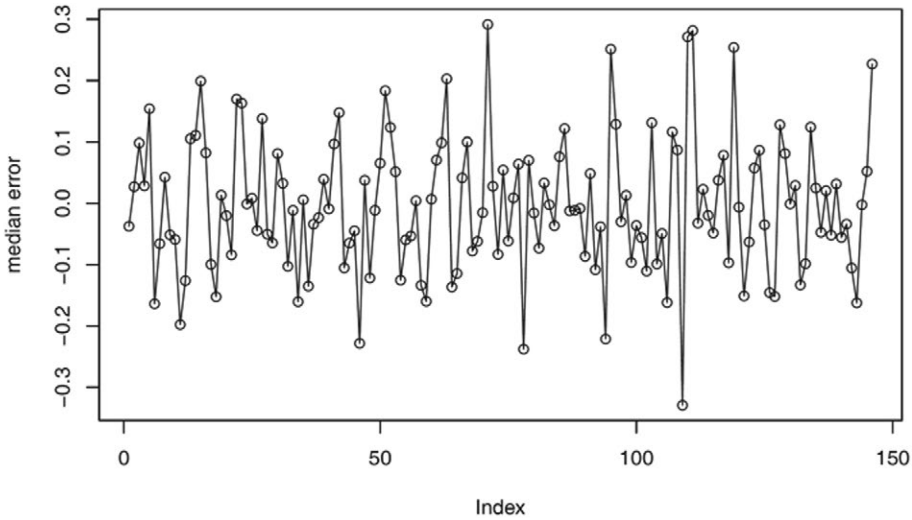

Figure S4. Prediction error of the median of the sample paths in log scale.

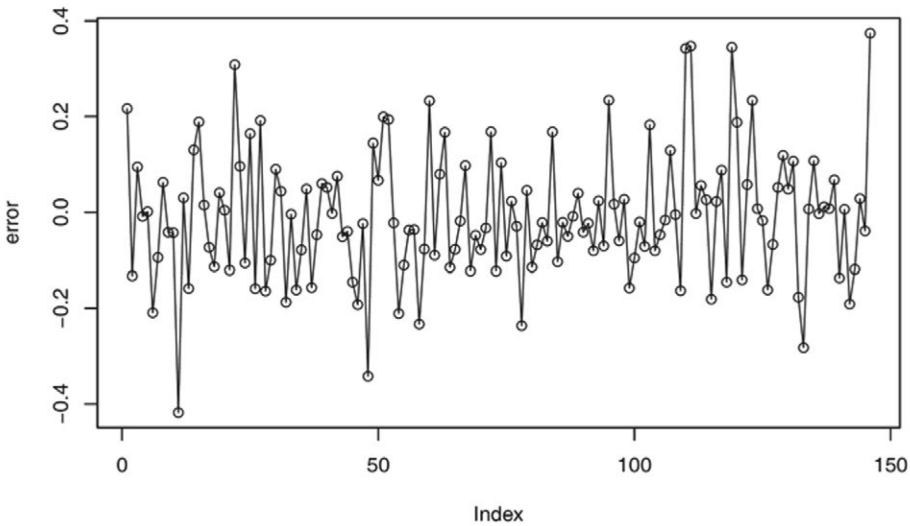

Figure S5. A sample path prediction error in log scale.

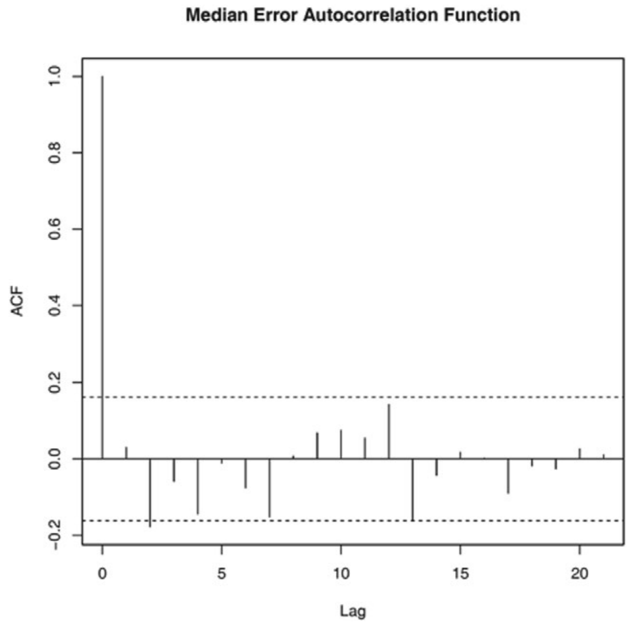

Figure S6. Median error ACF vanishes at first lag.

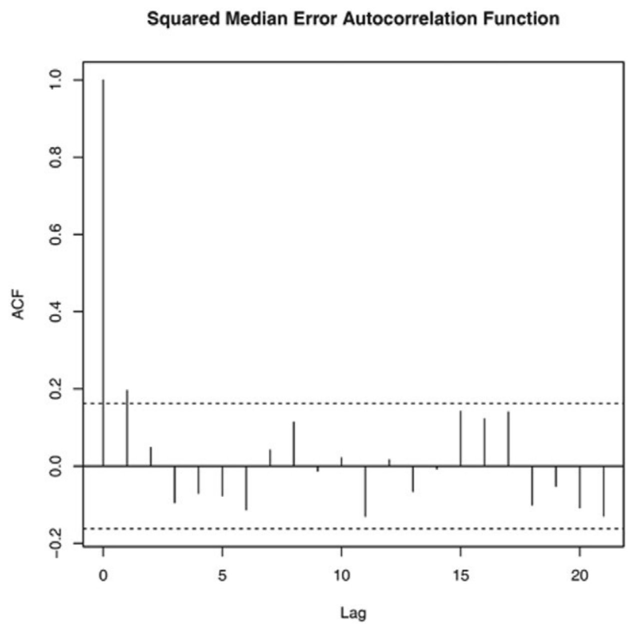

Figure S7. Squared median error ACF is detecting some dependency at first lag.

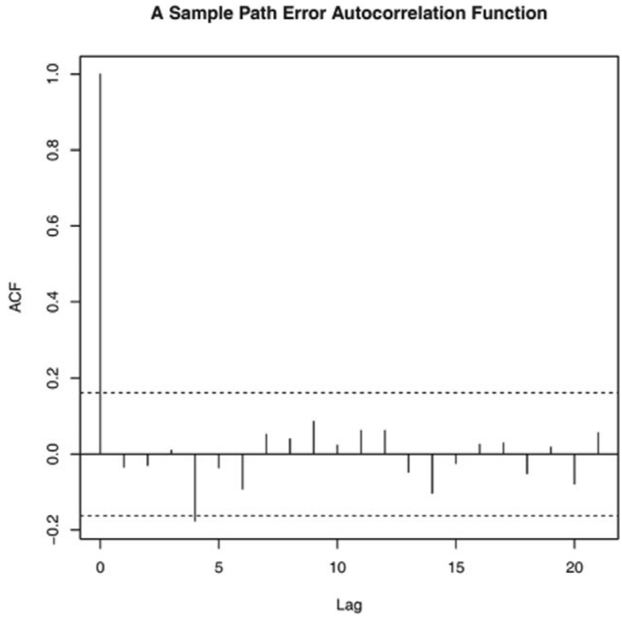

Figure S8. ACF for a sample path error indicates white noise.

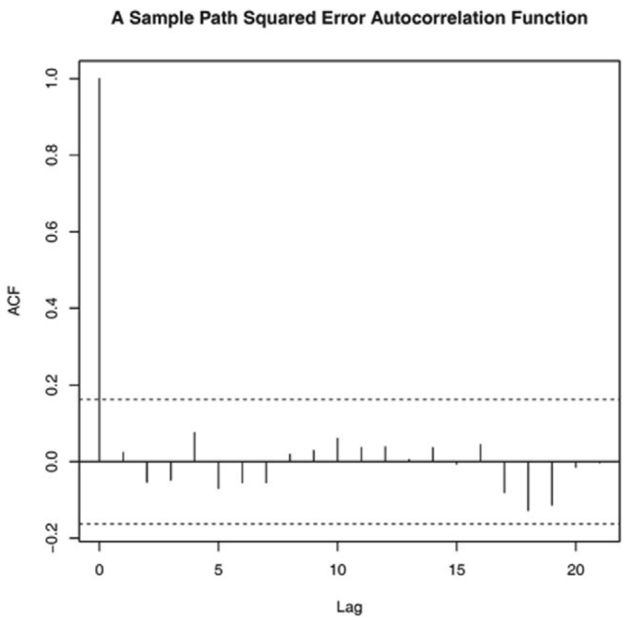

Figure S9. ACF for a sample path squared error indicates white noise.

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OLLI SALMENSUU

The potato, since its 16th century arrival from the Andes to temperate Europe, silently blessed all aspects of human life for its cultivators and consumers, including health, religion, trades, government, warfare, population and city growth. Year-round affordable potato nutrition meant food security and pro-poor development. Long-run determinants and short-run variability of prices are a key to policies which could increase potato use sustainably in present-day developing countries.

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