

# *Adopting a new technology: potatoes and population growth in the periphery<sup>†</sup>*

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Sweden's population doubled in size between 1750 and 1850 despite a century of stagnating per capita incomes and real wages, which has led many historians to attribute the population explosion to the introduction of the potato. This article provides the first systematic evidence on the potato's contribution to Swedish living standards and population growth. Potatoes at least doubled output per acre, and welfare ratios that account for potato consumption imply that they raised living standards significantly for labourers. Estimates that exploit regional differences in the suitability of land for cultivating potatoes further show that cities, counties, and rural parishes with more land suitable for potato cultivation experienced a sharp relative acceleration in population growth as the potato spread in the early nineteenth century. An expansion of the population was mainly driven by relative increases in fertility and, consistent with Malthusian predictions, there was no long-run impact on per capita incomes. According to these estimates, the introduction and spread of the potato can account for one-tenth of population growth between 1800 and 1850, thus suggesting that it was an important catalyst for the Swedish population explosion.

**A**n influential literature maintains that our world was governed by a Malthusian regime prior to the industrial revolution. Malthusian interpretations of preindustrial history emphasize that agricultural productivity improvements only led to transitory increases in living standards, which evaporated as population growth accelerated due to the positive and preventive checks highlighted by Malthus.<sup>1</sup> A fundamental challenge when confronting the Malthusian model with the historical record, however, is the endogeneity that riddles the link between agricultural productivity and population growth, as mounting population pressure or expanding urban centres may lead to an intensification of cultivation and the invention of new technologies that slows down the return to a Malthusian

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<sup>1</sup> Clark, *Farewell*; Ashraf and Galor, 'Dynamics'; Galor, *Unified growth theory*; Galor and Weil, 'Population'; Hansen and Prescott, 'Malthus'; Mokyr and Voth, 'Understanding'.

equilibrium.<sup>2</sup> Consequently, an important obstacle in understanding the empirical relevance of Malthusian mechanisms is the challenge involved in identifying exogenous changes in agricultural productivity in the preindustrial era.<sup>3</sup>

Potatoes were among the most revolutionary innovations in preindustrial agriculture. Yielding at least twice as many calories per acre relative to other staple crops, the introduction of the potato constituted a dramatic shock to European agricultural productivity.<sup>4</sup> After the Columbian Exchange, its subsequent spread thus constitutes a potentially important explanation for the expansion of cities and population in the Old World, distinct from explanations that emphasize the role of expanding trade opportunities and institutional change.<sup>5</sup> Indeed, Malthus had already argued that ‘countries are populous according to the quantity of human food which they produce’ and noted that another well-known contemporary predicted that the adoption of the potato would spur population growth:

Dr Adam Smith observes that if potatoes were to become the favourite vegetable food of the common people, and if the same quantity of land was employed in their culture as is now employed in the culture of corn, the country would be able to support a much greater population, and would consequently in a very short time have it.<sup>6</sup>

Against that background, this article examines the impact of the potato in eighteenth- and nineteenth-century Sweden, emphasizing a causal link between its introduction and the country’s explosive population growth in the early nineteenth century. The first step of the analysis examines the contribution of the potato to living standards through the lens of welfare ratios. Interestingly, while the standard of living during the early stages of the industrial revolution remains an area of substantial debate, the literature has largely neglected the role of the potato.<sup>7</sup> Yet, as a cheap source of calories, it became an increasingly important part of European diets: a Swedish worker consumed roughly half a kilo of potatoes on a daily basis in the mid-nineteenth century, northern English workers consumed around two kilos, and Irish pre-Famine diets commonly entailed a consumption of four to five kilos per adult male equivalent.<sup>8</sup> To elucidate the role of the potato, welfare ratios are calculated that relate nominal wages for agricultural day labourers to the cost of two different subsistence baskets: excluding and including potatoes respectively. While these welfare ratios unanimously reveal a very low living standard for Swedish labourers in the early nineteenth century, hovering around subsistence levels, they show that accounting for potato consumption leads to significant welfare

<sup>2</sup> Boserup, *Conditions*; Allen, *British industrial revolution*, pp. 57–79; Kopsidis and Wolf, ‘Agricultural productivity’.

<sup>3</sup> See, for example, Chaney and Hornbeck, ‘Economic dynamics’.

<sup>4</sup> Mokyr, *Lever*, p. 164; Gadd, *Agrara*, p. 256.

<sup>5</sup> In particular, see Nunn and Qian, ‘Columbian exchange’; eisdem, ‘Potato’s contribution’; North and Thomas, *Rise*; Acemoglu, Johnson, and Robinson, ‘Rise’. Also, see Mokyr, ‘Irish history’; Schmidt, Jensen, and Naz, ‘New crops’; Jia, ‘Weather shocks’, on the impacts of the potato.

<sup>6</sup> Malthus, *Essay*, p. 43.

<sup>7</sup> In particular, this debate has centred on the plight of British workers, with contributions by Lindert and Williamson, ‘English workers’ living standards’; Feinstein, ‘Pessimism’; Voth, ‘Longest years’; Clark, ‘Condition’; Allen, ‘Pessimism preserved’. Although there is an abundance of evidence that eighteenth-century people consumed new goods such as potatoes and sugar, Allen, ‘Great divergence’, p. 420, for example, notes that the scarcity of detailed budget information precludes their inclusion in a calculation of real wages.

<sup>8</sup> Myrdal, *Cost*, p. 119; Ó Gráda, ‘Ireland’s Great Famine’, p. 1; Allen, *British industrial revolution*, p. 47.

improvements, which ultimately may have helped labourers to maintain a life above subsistence.

An improved food situation due to the introduction of the potato not only affects existing interpretations of living standards during the early stages of Swedish industrialization, but also contributes to the literature arguing that careful adjustments of consumption baskets as new goods are introduced may affect the interpretation of European living standards in the preindustrial era, with potentially different effects on the evolution of living standards for different social groups.<sup>9</sup> Yet, while allowing for potato consumption leads to welfare increases relative to a grain-based diet, the fact that both welfare ratios exhibit a downward trend from the 1820s onwards is suggestive of mounting Malthusian pressures.

A standard Malthusian model predicts that an improved food situation should lead to a higher steady state population level, with only a temporary effect on per capita incomes that dissipates as the economy adjusts back to its Malthusian equilibrium. Against the backdrop of the spread of the potato, the Swedish population indeed doubled between 1750 and 1850, with a sharp acceleration in growth around the turn of the century when contemporary food budgets and historical production accounts suggest that widespread adoption took place. Yet, while the acceleration in population growth coincided with the adoption of potatoes, such a correlation may simply reflect reverse causality if potatoes were adopted to deal with an already expanding population.<sup>10</sup> To disentangle the causal impact of the potato, the empirical analysis therefore exploits regional differences in the suitability for potato cultivation as a source of exogenous variation in the potential impact of the potato after its introduction. By comparing changes in population in areas with land suitable for potato cultivation relative to areas with less suitable land, the identification strategy attributes differential changes after the potato's introduction in more suitable areas to the potato itself.

The main empirical analysis compares relative population changes in cities, counties, and rural parishes with land suitable for potato cultivation to less suitable areas, controlling for differential changes in other growth determinants. More suitable areas indeed saw an accelerated pace of population growth precisely around 1800, which is consistent with the historical evidence on the timing of widespread adoption of the potato. To shed further light on the underlying growth dynamics, the study examines standard Malthusian predictions that populations adjust to increases in agricultural productivity through fertility increases and mortality declines. Comparing parish-level changes in fertility and mortality suggests that population growth was the result of sharp relative increases in fertility and more muted declines in mortality after 1800. An important role of preventive checks and a lesser role of positive checks is consistent with recent evidence from eighteenth- and nineteenth-century Scandinavia and more broadly shows how a plausibly exogenous increase in agricultural productivity translates into an expanding population, which contributes to the vast body of work that examines the

<sup>9</sup> See Hersh and Voth, 'Sweet diversity'; Dittmar, 'Welfare impact'; Hoffman, Jacks, Levin, and Lindert, 'Real inequality'.

<sup>10</sup> Boserup, *Population*, p. 117, for example, argues that the introduction of the potato was an adaptation to increased population density rather than its cause.

indirect Malthusian implications in terms of real wages and vital rates.<sup>11</sup> Although the introduction of the potato led to increases in living standards and a sharp acceleration in population growth, however, additional evidence suggests that it was not mirrored in a similar increase in per capita incomes over the long term, which conforms with Malthusian predictions.

The remainder of the article is structured as follows. The next section describes historical accounts of the diffusion of the potato and population growth in Sweden, and estimates the potato's impact on living standards by calculating welfare ratios. Section II describes the data and provides the main empirical analysis documenting the potato's contribution to population growth and impact on vital rates. Section III concludes.

## I. Context and descriptive evidence

### I.1. *Introduction and diffusion of the potato*

Jonas Alströmer, an industrial entrepreneur and one of the founders of the Royal Swedish Academy of Sciences, is often credited with introducing the potato to Sweden in the early eighteenth century, though scattered evidence suggests it was cultivated earlier. Widespread adoption, however, did not take place until a century later. Agricultural historians such as Gadd and Utterström argue that this second important wave of diffusion began around 1800 and that the potato's economically significant breakthrough took place in the first decades of the nineteenth century.<sup>12</sup> Estimates of the increase in potato cultivation support these arguments: Sundbärg reports an increase in the harvest per capita from 32 to 275 kilos between 1801 and 1851, while Hellstenius states that potatoes constituted roughly 5 per cent of the seed (*utsädesbeloppet*) in 1802, which had increased to 34 per cent by 1869.<sup>13</sup> Evidence from food budgets similarly dates the breakthrough of the potato to around 1800, and suggests that it had become a central part of Swedish diets by mid-century, with an annual average consumption of 200 kilos among the male working class.<sup>14</sup>

Although potatoes were gradually introduced in many other European countries in the seventeenth and eighteenth centuries, there was a deeply rooted suspicion against the potato as a food source among Swedes. Yet, against the backdrop of falling living standards due to high grain prices in many areas in the late eighteenth century, county governors reported that the population's resistance to the potato began to fade between the 1770s and the 1790s.<sup>15</sup> As such, the potato was adopted at a time when the economy was exhibiting increasing signs of an impending ecological crisis, which was reflected in reductions in several metrics such as agricultural wages, heights, and yields.<sup>16</sup> An important contributing factor

<sup>11</sup> On Scandinavia, see Bengtsson and Dribe, 'New evidence'; Dribe, Olsson, and Svensson, 'Agricultural revolution'; Edvinsson, 'Vital rates'; Klomp and Möller, 'Post-Malthusian dynamics'; Lagerlöf, 'Malthus'. As examples of the broader literature, also see Nicolini, 'Malthus'; Crafts and Mills, 'Malthus'.

<sup>12</sup> See Gadd, *Agrara*, p. 256; idem, 'Agricultural revolution', p. 148; Utterström, *Jordbrukets*, p. 697.

<sup>13</sup> See Sundbärg, *Emigrationsutredningen: Betänkande*, p. 89; Hellstenius, 'Skördarna', p. 109. Also see Bohman, *Bonden*, pp. 82–6.

<sup>14</sup> Heckscher, *Economic history*, p. 173; Myrdal, *Cost*, p. 119.

<sup>15</sup> Heckscher, *Economic history*, p. 151.

<sup>16</sup> Bohman, 'Conditional crisis?'; Gadd, 'Agricultural revolution', pp. 143–4.

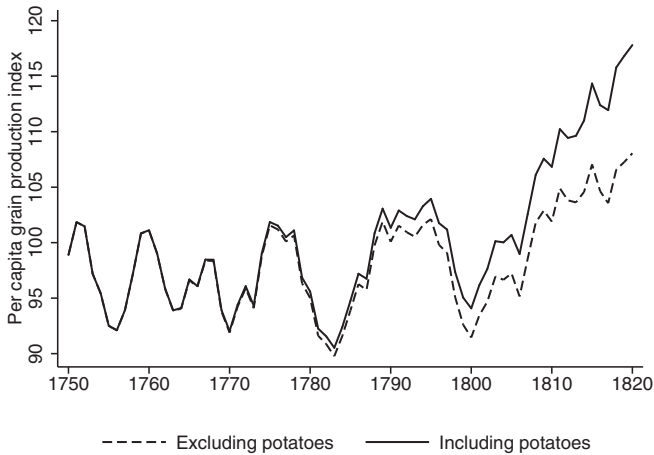


Figure 1. *Agricultural output in Sweden, 1750–1820*

Notes and sources: This figure shows five-year moving averages of per capita grain production, excluding and including potatoes respectively, based on estimates provided in Edvinsson, ‘Swedish harvests’. Each series is indexed to 1750/5 = 100.

to its increased cultivation was also the discovery in the 1820s that potatoes could be used to distil liquor, which inevitably fuelled rampant alcohol consumption in the countryside.<sup>17</sup> More broadly, the slow adoption of the potato reflected the widespread dissolution of the traditional villages and the open-field system that began around the turn of the century with the coming of the Enclosure Movement, which eased the introduction of new crops into rotations due to the individualization of decision making that followed in its wake.<sup>18</sup>

Agricultural productivity increased substantially as farms increasingly began to cultivate potatoes. After half a century of near-stagnant grain productivity, the introduction of the potato in the early nineteenth century was associated with a significant increase in per capita production (see figure 1). Productivity advances partly reflected the fact that yields were substantially higher relative to other commonly grown staple crops: in the early nineteenth century, for example, the average seed-yield ratio for potatoes exceeded seven, while yields of barley, oats, rye, and wheat ranged between four and five.<sup>19</sup> Moreover, cultivating potatoes was simple and required no major changes to existing agricultural practices; its growth requirements allowed additional marginal land to be cultivated, and by reducing the area required to sustain a household it freed up land that could be used to cultivate cereals.<sup>20</sup> Although potato growing required higher labour input, this was compensated for by the fact that potatoes did not require drying, threshing,

<sup>17</sup> Gadd, *Agrara*, pp. 259–61; Utterström, *Jordbrukets*, pp. 698–9.

<sup>18</sup> See Gadd, *Agrara*, pp. 283–304. An important institutional factor that promoted the increased cultivation of potatoes was the fact that the crop typically was not part of the tithes. For example, in the southernmost province, Scania, an 1808 royal ordinance declared that the clergy was not entitled to tithes from potatoes (see Olsson and Svensson, ‘Agricultural growth’, p. 283), which increased the net return of cultivating potatoes relative to other staple crops.

<sup>19</sup> Morell, Gadd, and Myrdal, ‘Statistical appendix’, tab. 6.1.

<sup>20</sup> As pointed out by an anonymous referee, however, potato growing required the development or rediscovery of several complementary technologies such as new forms of storage, as reflected in the breakthrough of ‘potato cellars’, and the increased use of ard ploughs and spades.

or milling prior to consumption. Gadd estimates that these virtues of the potato increased calorie production per unit of land by a factor of at least 2.5–3, which suggests that food production indeed could have increased on a massive scale in the wake of the widespread adoption of the potato.<sup>21</sup>

### 1.2. Potatoes and population growth

Sweden's population expanded rapidly as potato cultivation spread throughout the country: the population nearly doubled between the mid-eighteenth and the mid-nineteenth century—increasing from some 1.8 to 3.5 million—with a sharp acceleration in growth around the turn of the century when widespread adoption of the potato began. In particular, the growing population was driven by an expansion of the landless classes, leading many historians to characterize the first half of the nineteenth century as one of increasing proletarianization of the rural population.<sup>22</sup> Between 1750 and 1850, the share of non-property-owning classes such as crofters, cottars, and day labourers—referred to as the 'potato people' by nineteenth-century aristocrats—almost quadrupled, thus increasing their share of the rural population to about half.<sup>23</sup>

Among Swedish historians, the accelerating pace of population growth and the expansion of the rural lower classes is often partly attributed to the increased availability of food due to the potato. Most famously, the poet Esaias Tegnér argued in 1833 that the acceleration was due to 'peace, the vaccine, and the potato', which remains an oft-cited explanation.<sup>24</sup> Although the reduced incidence of war and an improvement in the epidemic climate may have contributed to population growth through a reduction in mortality, the introduction of the smallpox vaccine in 1801 and compulsory vaccination laws in 1816, however, seems to have had limited effects on population growth, though it significantly accelerated the downward trend in infant mortality rates.<sup>25</sup> While this leaves significant room for the potato as an explanation, curiously there is no systematic evidence on its contribution to population growth. Along similar lines, while most Swedish economic historians argue that real wages were relatively stagnant during the first half of the nineteenth century, such real wage series do not take into account the increased availability of cheap calories from the potato, which suggests that they may underestimate living standards in this period.<sup>26</sup>

<sup>21</sup> See Gadd, *Agrara*, p. 256. Similarly, Arthur Young's survey of English farming communities in the 1760s documented that to supply a family of two adults and three children with their daily caloric needs, potatoes required less than a third of the acreage compared to barley, oats, and wheat; see Nunn and Qian, 'Potato's contribution', tab. I.

<sup>22</sup> See Winberg, *Folkökning*; Wohlin, *Jordbruksidkande*.

<sup>23</sup> See Schön, *Sweden's road to modernity*, p. 48; Gadd, *Agrara*, pp. 221–30; idem, *Järn*, p. 345.

<sup>24</sup> See, for example, Montgomery, *Industrialismens*, p. 12; Utterström, *Jordbrukets*, p. 43; Schön, *Sweden's road to modernity*, p. 46. Agricultural historians similarly have emphasized the role of the potato in the expansion of the rural landless population, arguing that potatoes increased the potential calorie production per hour, thus increasing the potential surplus extraction, which gave peasants incentives to lease land to crofters and cottager households; see Gadd, *Järn*, p. 345; idem, *Agrara*, p. 230.

<sup>25</sup> See Fridlitzius, 'Mortality decline'; Ager, Worm Hansen, and Sandholt Jensen, 'Fertility'.

<sup>26</sup> On wage developments see, for example, Utterström, *Jordbrukets*, pp. 876–84; Jörberg, *Prices*, vol. 2, pp. 334–46; Söderberg, 'Real wages'. Economic historians are, however, well aware of the potential problem that potatoes are not included in the calculation of real wage series. Jörberg, 'Levnadsstandarden', p. 9, for example, notes explicitly that the lack of potato prices may affect the computation of real wages as they constituted a

### I.3. *The potato's contribution to living standards: a real wage approach*

Economic historians traditionally rely on real wages to approximate the living standards of consumers. To give real wages an absolute interpretation, welfare ratios are constructed that relate nominal wages for day labourers to a subsistence basket that mainly consists of expenditure on cloth, food, and fuel.<sup>27</sup> A welfare ratio is constructed by calculating the number of baskets a labourer can buy for his family, where a welfare ratio of one corresponds to the level of income required to sustain a family at subsistence. Similar in spirit to studies that adapt baskets to reflect the fact that different goods are consumed in different countries due to varying tastes and relative prices,<sup>28</sup> two alternative subsistence baskets are constructed: one mainly based on rye, the cheapest and most widely consumed grain, and one based on potatoes.

An important role of the potato in the subsistence basket is highlighted by the fact that potatoes constituted a cheaper source of calories than grain. Against that backdrop, it is not surprising that they became an increasingly important part of Swedish diets: Myrdal, for example, estimates an average consumption of 200 kg of potatoes per worker per year in the first half of the nineteenth century.<sup>29</sup> Furthermore, while these levels reflect the average level of consumption, potatoes probably had greater importance for the lower social strata, further highlighting the relevance of their inclusion in a subsistence basket.<sup>30</sup> As aptly summarized by Sandberg and Steckel: 'It seems apparent that the population preferred to eat bread, but low incomes, or the attraction of low potato prices, induced them to eat potatoes instead.'<sup>31</sup>

To calculate welfare ratios, data on prices and wages are collected from a variety of sources, which are described in more detail in appendix I. Day wages for agricultural labourers are based on the widely used series from Jörberg, and prices are mainly drawn from Jörberg and Myrdal.<sup>32</sup> As the prices required to construct the baskets are not available for the whole country, prices and wages from the southernmost county of Malmöhus are used; this county had an abundance of land suitable for potato cultivation that makes it a highly relevant case in light of the subsequent empirical analysis. For both baskets, this study follows Allen in assuming daily consumption of 2,099 kcal per day, which is mainly derived from grain and small amounts of animal protein (see table 1).<sup>33</sup> While this level

growing share of expenditure over the first half of the nineteenth century. Interestingly, Sandberg and Steckel, 'Overpopulation', p. 11, argue that net nutrition recovered after the Napoleonic Wars at least until 1840, which is reflected in increases in soldier heights for cohorts born in this period, which is 'compatible with a real wage level for day workers similar to that in the middle of the eighteenth century because of the rapid spread of the potato as a field crop'. Yet they do not provide any direct evidence to support a link between living standards and the diffusion of the potato.

<sup>27</sup> See Allen, 'Great divergence'; idem, 'Poverty lines'.

<sup>28</sup> Allen, 'Great divergence'; idem, 'Poverty lines'; Özmucur and Pamuk, 'Real wages'.

<sup>29</sup> Myrdal, *Cost*, p. 119.

<sup>30</sup> See, for example, Utterström, *Jordbrukets*, pp. 698, 700. While there is no clear quantitative evidence on a social gradient in consumption for Sweden, evidence from other countries is highly suggestive of such a pattern. Ó Gráda, 'Ireland's Great Famine', p. 2, for example, cites evidence from Bourke, *Visitation*, and Mokyrt, 'Irish history', that Irish labourers consumed more than three times as many potatoes per capita as large-scale farmers or professionals in the early 1840s.

<sup>31</sup> Sandberg and Steckel, 'Industrialization', pp. 142–3.

<sup>32</sup> Jörberg, *Prices*; Myrdal, *Cost*.

<sup>33</sup> Allen, 'Poverty lines'.

Table 1. *Subsistence baskets*

|                  | <i>Rye-based</i> | <i>Potato-based</i> |
|------------------|------------------|---------------------|
| Rye              | 170 kg           | 0 kg                |
| Peas             | 20 kg            | 20 kg               |
| Potatoes         | 0 kg             | 560 kg              |
| Beef             | 5 kg             | 5 kg                |
| Butter           | 3 kg             | 3 kg                |
| Cloth            | 3 metres         | 3 metres            |
| Candles          | 1.3 kg           | 1.3 kg              |
| Soap             | 1.3 kg           | 1.3 kg              |
| Lamp oil         | 1.3 litres       | 1.3 litres          |
| Fuel             | 2 MBTU           | 2 MBTU              |
| Calories per day | 2,099 kcal       | 2,099 kcal          |

*Notes and sources:* This table reports two alternative subsistence baskets based on the basket reported in Allen, 'Poverty lines', tab. 1, used to construct the welfare ratios shown in fig. 2. See app. I for a further description of the underlying data.

of caloric intake exceeds that of an absolute subsistence line at some 1,500 kcal per day,<sup>34</sup> it corresponds with the consumption necessary to maintain the level of physical activity of a typical nineteenth-century labourer, which also aligns with the activity levels used in the construction of modern poverty lines.<sup>35</sup> A crucial issue in constructing the alternative basket is the weight assigned to potatoes: to identify the upper bound gain due to the potato in a transparent manner, it is simply assumed that a labourer shifts all his consumption of grain to potatoes.<sup>36</sup>

Figure 2 shows the welfare ratios during the half-century after the introduction of the potato. In the early nineteenth century, welfare ratios using the rye-based basket often fall below unity in individual years, suggesting a life below or close to subsistence.<sup>37</sup> A low standard of living echoes the fact that conventional real wages reached their lowest level since the early modern period in these years.<sup>38</sup> Potatoes, however, comfortably enabled a life above subsistence levels: welfare ratios calculated using the alternative basket are well above unity, even during years when the rye-based diet apparently would require families to find additional sources of income, or alternative types of food, to maintain life at subsistence. An increase in welfare ratios after allowing for the consumption of potatoes suggests that the introduction of the potato into Swedish diets may indeed reflect a 'massive, unrecognized (and unrecorded) consumer surplus'.<sup>39</sup>

<sup>34</sup> Clark, *Farewell*, p. 23.

<sup>35</sup> See Allen, 'Poverty lines'.

<sup>36</sup> Although this level of consumption is unlikely to have been sustained for meaningful periods of time, a high level of potato consumption is observed in, for example, records of payments in kind (*stat*) on the estates in the southern parts of the country where 300–500 kg of potatoes were not uncommon in the 1860s; see Bagge, Lundberg, and Svenilsson, *Wages*, pp. 388–9. Moreover, the nutritional superiority of the potato means that humans can survive on a diet solely consisting of potatoes as long as it is complemented with a source of protein such as herring or milk (see, for example, Gadd, *Agrara*, p. 257), which suggests that the estimated welfare ratios may be meaningful in the sense that they reflect a composition of consumption that could have been sustained for limited periods of time.

<sup>37</sup> Welfare ratios could increase in a number of ways; for example, if a labourer works more days than the 250 that constitute the baseline, by expanding production within the household, or by children and women taking on paid work in the labour market.

<sup>38</sup> See Söderberg, 'Real wages'.

<sup>39</sup> Sandberg and Steckel, 'Industrialization', p. 143.

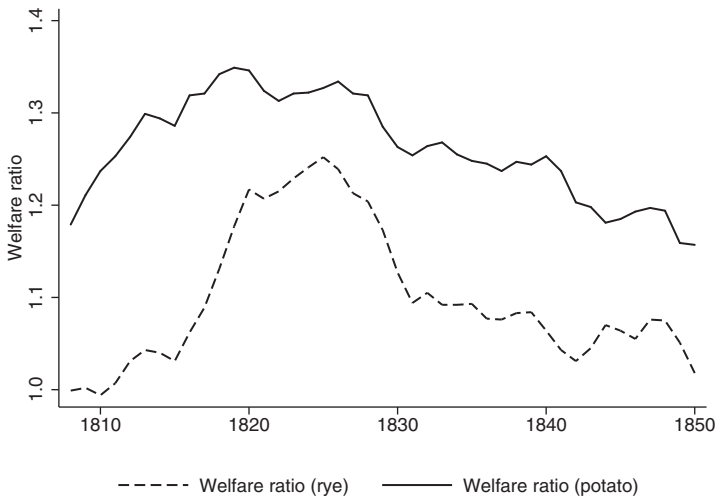


Figure 2. *Welfare ratios*

Notes: This figure shows 11-year moving averages of the welfare ratios constructed on the basis of wages from Jörberg, *Prices*, and the rye- and potato-based subsistence baskets in tab. 1 respectively. Note that both baskets are scaled by a factor of four to yield the consumption levels for a family, and that 5% of the cost of the rye-based basket is added to each basket’s total cost to account for housing. A value of one should be interpreted as the level at which a family could exactly maintain a subsistence level of consumption, whereas values above (below) unity indicate a surplus (deficit) over subsistence.

Sources: See the main text and app. I for further details on the underlying data and construction of the welfare ratios.

A positive contribution of the potato to welfare ratios more broadly chimes well with the argument that it became an increasingly crucial source of food intake in the early nineteenth century, particularly for the lower social strata living close to subsistence.<sup>40</sup> In particular, the fact that the increased availability of potatoes raised the potential calorie consumption contrasts with arguments that there was no notable improvement in terms of nutritional conditions prior to the mid-nineteenth century.<sup>41</sup> Instead, these results suggest that food intake improved in the first decades of the nineteenth century as claimed by, for example, Sandberg and Steckel, and are consistent with the argument that the food situation improved after the introduction of the potato.<sup>42</sup> However, even if the introduction of potatoes into diets unambiguously served to raise the welfare of the rural population, the fact that both welfare ratios exhibit declines starting in the 1820s suggests that the welfare gains due to the potato’s introduction may have been transitory, as implied by Malthusian logic. This raises the question of whether the introduction of the

<sup>40</sup> See Gadd, ‘Agricultural revolution’, p. 148; Utterström, *Jordbrukets*, p. 700. An additional channel through which potatoes may have increased living standards is as a way to smooth consumption in times of sharp increases in grain prices. As documented in Hellstenius, ‘Skördarna’, poor harvests were a recurring scourge throughout the eighteenth and nineteenth century, with price increases routinely leading to drops in calorie intake of 10–20% for the poorer parts of the population; Bengtsson and Dribe, ‘New evidence’, p. 351. Whether potatoes may have provided relief during such episodes critically hinges on the similarity in price movements of potatoes and other cereals. Between 1830 and 1850, the correlation between annual changes in the (*ln*) price of potatoes and rye reported in Myrdal, *Cost*, in Malmöhus county is about 0.24, which suggests a relatively limited overlap and that potatoes thus may also have provided opportunities for poor people to substitute potatoes for cereals during years of elevated grain prices.

<sup>41</sup> Fridlitzius, ‘Mortality decline’.

<sup>42</sup> Sandberg and Steckel, ‘Overpopulation’; Gadd, *Agrara*, p. 230; Montgomery, *Industrialismens*, p. 34.

potato constituted a lever for the population to expand, which could potentially explain the mounting downward pressure on living standards as the economy gradually adjusted to a Malthusian equilibrium.

## II. Empirical analysis

To analyse the contribution of the potato to population growth, a city-, county-, and parish-level dataset is constructed on regional variation in the suitability for growing potatoes, population, and vital rates. This section describes the sources used to construct the data and then presents the main results, showing that population growth indeed accelerated in areas suitable for potato cultivation after 1800, which mainly reflected increases in fertility and more modest reductions in mortality broadly consistent with Malthusian predictions.

### II.1. Data

As the foundation for the empirical analysis, this study builds on work by Nunn and Qian and exploits regional differences in suitability for potato cultivation, which constitutes a source of variation in *potential* potato yields.<sup>43</sup> Unlike *observed* yields, the variation in suitability for cultivating potatoes constitutes an exogenous source of variation in agricultural productivity after the introduction of the potato since it is driven by, for example, precipitation patterns and soil nutrients rather than endogenous factor inputs or technological adjustments.

To measure suitability for growing potatoes, geospatial raster data from the UN Food and Agriculture Organization's Global Agro-Ecological Zones (FAO-GAEZ) database are used.<sup>44</sup> These provide information at the grid-cell level on suitability for growing various crops under medium input and rain-fed conditions, which presumably approximates historical conditions. For the purposes of this article, the FAO-GAEZ provides data for the entire globe divided into 2.2 million grid cells ( $0.5 \times 0.5$  degrees large) that are classified according to their suitability for growing potatoes based on information on climate constraints (cloud cover, frequency of wet days, ground-frost frequency, temperature range, wind speed, and so on), soil quality (fertility, drainage, and so on), and terrain slopes. Each cell is then categorized based on the maximum attainable yield predicted by these characteristics on a scale ranging from 'not suitable' to 'very high' suitability. Matching the FAO-GAEZ data to a historical map of Swedish administrative boundaries obtained from the Swedish National Archives<sup>45</sup> makes it possible to calculate the share of land in each county, city, and parish that falls above these suitability cutoffs. In the analysis, three different cutoffs are used to define suitability: the share of land that is at least 'highly suitable', 'suitable', and 'moderately suitable', which corresponds to the share of land that is classified as at least being of high, good, or medium suitability respectively according to the FAO-GAEZ suitability index (see figure 3).<sup>46</sup> Additional GIS data are drawn from

<sup>43</sup> Nunn and Qian, 'Potato's contribution'.

<sup>44</sup> UN Food and Agriculture Organization (FAO), 'GAEZ, Global Agro-Ecological Zones', <http://www.fao.org/nr/gaez/en/> (accessed on 18 June 2018).

<sup>45</sup> Riksarkivet, 'Information tillgänglig för vidareutnyttjande', <https://riksarkivet.se/psidata> (accessed on 18 June 2018).



**Figure 3.** *Suitability for cultivating potatoes*

*Notes:* This map shows parish-level differences in suitability for cultivating potatoes, based on the FAO-GAEZ data described in more detail in section II.1. The four shades correspond to a parish having no land suitable for potato cultivation (lightest shade), to having some moderately suitable, suitable, or highly suitable (darkest) land.

*Sources:* See section II.1 for further details on the underlying data.

Table 2. *Potato suitability and yields, c. 1810*

| Share of land:        | A. Potato yields    |                     |                     | B. Yields for other crops |                      |                   |                      |                     |
|-----------------------|---------------------|---------------------|---------------------|---------------------------|----------------------|-------------------|----------------------|---------------------|
|                       | (1) Potato          | (2) Potato          | (3) Potato          | (4) Barley                | (5) Oats             | (6) Peas          | (7) Rye              | (8) Wheat           |
| ≥ Highly suitable     | 2.245***<br>(0.438) |                     |                     |                           |                      |                   |                      |                     |
| ≥ Suitable            |                     | 1.057***<br>(0.348) |                     | -0.152<br>(0.310)         | -1.012***<br>(0.253) | -0.345<br>(0.477) | -1.577***<br>(0.330) | -0.849**<br>(0.300) |
| ≥ Moderately suitable |                     |                     | 1.350***<br>(0.306) |                           |                      |                   |                      |                     |
| Average yield         | 6.58                | 6.58                | 6.58                | 4.62                      | 4.52                 | 4.45              | 4.45                 | 4.63                |
| Observations          | 2,133               | 2,133               | 2,133               | 2,241                     | 2,022                | 1,793             | 2,290                | 1,486               |
| R <sup>2</sup>        | 0.033               | 0.018               | 0.045               | 0.001                     | 0.062                | 0.004             | 0.100                | 0.028               |

Notes: This table presents OLS estimates from regressing parish-level yields (*korntal*) from Andersson Palm, *Jordbruksstatistik*, on the share of land that is at least highly suitable, suitable, or moderately suitable for potato cultivation for all parishes that cultivated potatoes in cols. 1–3 and for the subset of parishes that cultivated each crop denoted in the top row in cols. 4–8. Standard errors clustered at the county level are reported in parentheses. Statistical significance is denoted by: \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.10$ .

Sources: See section II.1 for further details on the underlying data.

the CGIAR SRTM dataset, while boundary data are based on the GADM database and historical maps from the Swedish National Archives.<sup>47</sup>

A crucial assumption in using these data is that there is a link between these suitability measures and the productivity of potato cultivation in the nineteenth century, which provokes the question whether the contemporary nature of the FAO-GAEZ data accurately captures historical differences in potato yields. In order to evaluate this assumption, data on yields (*korntal*) are collected from Andersson Palm, who reconstructed parish-level data for a variety of agricultural outcomes around 1810.<sup>48</sup> Table 2, panel A, reports ordinary least squares (OLS) estimates from regressing potato yields on the share of land that is at least highly suitable, suitable, and moderately suitable for potato cultivation respectively. All estimates suggest that parishes with more suitable land indeed exhibit higher potato yields, which supports the assumption that the suitability data reflect an important determinant of the productivity of potato cultivation. As evident in panel B, there is no positive link between suitability for cultivating potatoes and yields of other crops, which is further supported by quantitative evidence based on other sources.<sup>49</sup> Moreover, the fact that the three counties with the highest potato yields according to Morell et al. (Blekinge, Kristianstad, and Malmöhus) all have an abundance of suitable land as evident in figure 3,<sup>50</sup> and the fact that

<sup>46</sup> For counties and (rural) parishes, I simply calculate the share of land that falls in each suitability category, while I use information on the constituent parishes of each urban municipality to identify the land suitability for urban areas, in order to allow for the fact that most urban areas were dependent on their surroundings for their food supply.

<sup>47</sup> Additional GIS data are obtained through DIVA-GIS, <http://diva-gis.org/Data> (accessed on 18 June 2018).

<sup>48</sup> Andersson Palm, *Jordbruksstatistik*.

<sup>49</sup> In particular, regression results using the county-level data on seed-yield ratios in 1802/5 from Morell, Gadd, and Myrdal, 'Statistical appendix', tab. 6.3, suggest that potato yields were significantly higher in counties with more land suitable for potato cultivation, while these counties did not exhibit higher yields for barley, rye, or wheat (not reported). Furthermore, pairing the county-level data on potato harvests from Statistiska Centralbyrån, *Minnesskrift*, tab. 1, with the suitability data suggests that counties with more suitable land saw larger potato harvests per capita in 1810 and 1820, while the increase in the harvest per capita was significantly higher in more suitable counties between these years (not reported).

<sup>50</sup> Morell et al., 'Statistical appendix'.

one of the most suitable counties (Blekinge) saw rapid cultivation of potatoes from the early nineteenth century and as late as 1870 was the area where potato cultivation occupied the largest share of the available acreage, is further suggestive of a link between cultivation and suitability.<sup>51</sup> More broadly, Utterström notes that after the 1820s, the potato became increasingly important particularly in Blekinge, Halland, Kristianstads, Malmöhus, Skaraborgs, and Älvsborgs county, which are precisely those areas that have an abundance of suitable land, as depicted in figure 3.<sup>52</sup> Importantly, evidence that differences in soil suitability predict historical variation in the productivity of potato cultivation thus suggests that the modern nature of the suitability data does not introduce a bias into the subsequent analysis.<sup>53</sup>

To account for differences in the suitability for growing other staple crops, analogous measures of the share of land that is highly suitable for growing barley, rye, and wheat respectively are created, based on similar data from the FAO-GAEZ. Suitability for cultivating these crops is nearly perfectly correlated, with a raw correlation above 0.96 across parishes.<sup>54</sup> However, the different climatic and soil requirements of potatoes are reflected in a lower correlation between potato suitability and suitability for growing barley, rye, and wheat (their raw correlations range between 0.42–0.45), consistent with the argument that one of the main virtues of the potato was that it could be cultivated on land that was less suited for other crops. Moreover, a limited overlap between the suitability for cultivating potatoes and other staple crops importantly suggests that the impact of the potato can potentially be identified by comparing relative changes in areas suitable for cultivation.

To analyse the potential link between soil suitability and population growth, this study draws upon Sweden's uniquely rich historical population data. County-level population data are available for the years 1750, 1754, 1760, 1766, 1769, and 1772, with data available for every fifth year for the period 1795–1850, as reported by Statistiska Centralbyrån.<sup>55</sup> Although the population data are of high quality compared to those available for other countries, it has been shown that the recorded population for the eighteenth century in most cases is too low. To account for this, county figures between 1750 and 1810 are scaled to match the adjusted totals provided by Sundbärg, which form the basis for the 'official' Swedish

<sup>51</sup> See Gadd, *Agrara*, p. 256.

<sup>52</sup> See Utterström, *Jordbrukets*, p. 698.

<sup>53</sup> Although the estimates and the historical literature both emphasize the greater productivity of potato cultivation in areas with more suitable land as reflected in the FAO-GAEZ data, potatoes were also sometimes cultivated on marginal soils where other grains could be grown only with great difficulty. While potatoes in some instances proved important in such areas, yields were likely to have been substantially lower than in areas with more suitable land.

<sup>54</sup> Because the suitability measures for growing barley, rye, and wheat are highly correlated, I create a composite suitability measure to avoid multicollinearity issues in the analysis below by simply taking the average share of land that is highly suitable for cultivation of these crops.

<sup>55</sup> Statistiska Centralbyrån, *Historisk*, p. 49. Prior to 1779, Värmland and Örebro county was part of Närke och Värmland county, the counties of Gävleborg and Jämtland were part of Västernorrland county prior to obtaining county rights in 1762 and 1810 respectively, and Norrbotten county was part of Västerbotten county prior to 1810. Using population weights from the first year in which each of these counties reported populations separately, I extrapolate populations backward so that 24 consistent counties (after merging Stockholm city and county) are observed over the entire period.

population statistics, so that the total population of the 24 counties sums to the adjusted national figures.<sup>56</sup>

City-level data are drawn from Lilja and Nilsson for the respective periods 1750–1810 and 1810–50, for which they report adjusted total population counts based on information from poll-tax registers (*mantalslängder*) and the official population statistics. A total of 82 cities exist, and observations are made of these cities' populations in 1750, 1770, and at decadal intervals between 1800 and 1850.<sup>57</sup>

Parish-level population data are available from the historical registers maintained by the Tabular Commission, which are based on information collected from the parish clergy, typically including a full population count as well as information on births, deaths, and marriages at three- or five-year intervals.<sup>58</sup> While the Tabular Commission data contain information on several thousand unique geographical units, these are highly unbalanced. To reduce concerns that areas that grew rapidly became more likely to enter the data over time, the main sample used in the analysis focuses on a restricted set of 718 consistently defined rural parishes observed at five-year intervals between 1750 and 1850.<sup>59</sup>

## II.2. Main results

As a first step to identify the contribution of the potato to population growth, a flexible difference-in-differences specification is estimated, which compares population changes in areas with soils suitable for potato cultivation relative to those with less suitable soils. The main estimating equation takes the following form:

$$\ln(P_{it}) = \alpha_i + \lambda_t + \delta_t \text{Potato}_i + \varepsilon_{it} \quad (1)$$

where  $P$  is the population of county, city, or parish  $i$  in year  $t$ . The main variable of interest is *Potato*, which corresponds to the share of land that is at least suitable for growing potatoes, with the coefficient  $\delta_t$  returning the average difference in population for a county, city, or parish with all of its land suitable for potato cultivation relative to those with no suitable land in year  $t$  measured relative to the omitted base year 1750. By comparing changes over time in the population of areas with a higher share of land suitable for potato cultivation relative to those with less suitable soils, the identifying assumption is that areas with suitable soils would have developed similarly to areas with less suitable soils had it not been for the introduction and spread of the potato. Although the identifying assumption is not directly testable, it would be indirectly supported if there are no differences in

<sup>56</sup> See Sundbärg, *Bevölkerungsstatistik*. As the reported county-level population for Blekinge does not include the city of Karlskrona in the period prior to 1769, I adjust the population upwards for the period 1750–69 based on the share of the county population living in Karlskrona in 1770, as reported by Lilja, *Städernas*.

<sup>57</sup> Lilja, *Städernas*; Nilsson, *Historisk*. Unfortunately, city populations are unavailable for the year 1750 so for that year city sizes are interpolated on the basis of data for 1730 and 1770.

<sup>58</sup> The parish-level data were obtained from the Demographic Database, CEDAR, Umeå University, <http://www.cedar.umu.se/english/ddb> (accessed on 18 June 2018).

<sup>59</sup> Not all parishes reported total populations counts every fifth year, so I average the data for each parish using data in adjacent years. Furthermore, as not all parishes reported demographic outcomes for these years, the sample used to examine changes in fertility and mortality is slightly smaller. An earlier version of the article showed that results remained very similar in an unbalanced sample including virtually all parishes that reported data to the Tabular Commission.

population growth prior to the adoption of the potato (that is, if  $\delta_{t < 1800} = 0$ ), and we will return to this topic below to assess whether this assumption is likely to hold.

County, city, or parish fixed effects ( $\alpha_i$ ) make it possible to control for time-invariant and region-specific characteristics, such as persistent differences in geography, social structure, or the type of property rights, that may have contributed to differences in population and that are likely to be correlated with differences in soil suitability. Year fixed effects ( $\lambda_t$ ) capture factors that vary over time but affect all areas in a similar way; potentially important examples include the introduction of smallpox vaccination in 1801, the famine years in the early 1770s, and national changes in trade policy in the nineteenth century. Throughout the analysis, standard errors are clustered at the county, city, or parish level to account for autocorrelation in the outcomes and heteroscedasticity.<sup>60</sup>

Figure 4a graphically depicts the county-level estimates of the  $\delta_t$ -coefficients from equation 1 and a 95 per cent confidence bound. In the eighteenth century, there are no statistically significant differences in population changes between areas with suitable and less suitable soils, and estimated differences are close to zero in magnitude. Importantly, this suggests that prior to the widespread adoption of the potato in the early nineteenth century, counties with and without soils suitable for cultivating potatoes were growing at a similar rate, which supports the identifying assumption of the analysis. Around the turn of the century, however, population growth started to accelerate in counties with more suitable soils. Over the first half of the nineteenth century, counties with more land suitable for potato cultivation experienced substantial relative increases in population and the cumulative increase by 1850 corresponds to about a 39 per cent (0.33 log points) larger population in a county where all land is suitable for cultivating potatoes relative to a county with no suitable land.

As shown in figures 4b and 4c, which graph estimates from analogous regressions based on the population of cities and rural parishes respectively, the relationship is very similar: while there is no clear evidence of differential growth rates prior to the introduction of the potato, there is a sharp break in population growth across both cities and parishes after the introduction of the potato around 1800. Arguably, the fact that there is an acceleration in population growth in areas with soils suitable for potato cultivation precisely around 1800, when contemporary production accounts and food budgets suggest that widespread adoption of the potato took place as described in section I.1, is seemingly consistent with these changes being driven by the introduction of the potato. Yet, for this interpretation of the empirical patterns to be valid it requires that there are no omitted factors that are correlated with the cross-sectional distribution of land suitable for potato cultivation *and* differentially affected population growth after the turn of the century, which is evaluated empirically below.

As these empirical estimates indicate that the impact of the potato was visible from 1800, however, it suggests that this year can be used as a (conservative) cutoff to analyse the effects of the potato before and after its introduction in a simple difference-in-differences framework:

$$\ln(P_{it}) = \alpha_i + \lambda_t + \delta(Potato_i \times Post_t) + \mathbf{X}_{it}\beta + \varepsilon_{it} \quad (2)$$

<sup>60</sup> See Bertrand, Duflo, and Mullainathan, 'Differences-in-differences estimates'.

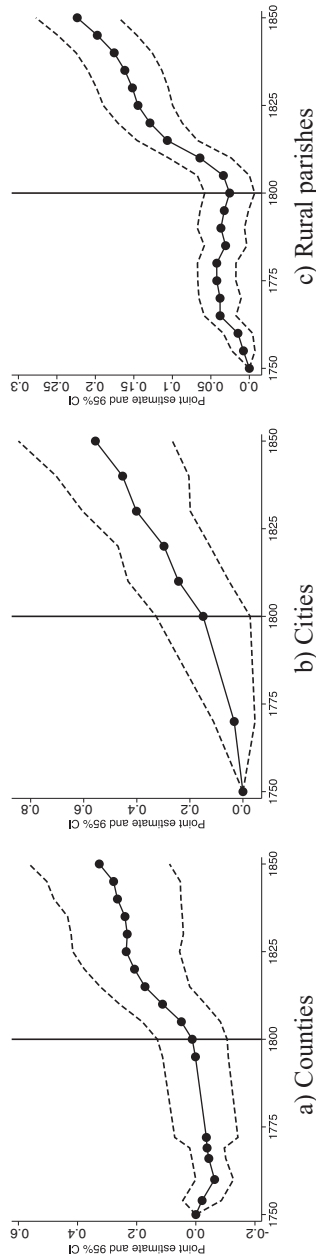


Figure 4. Potatoes and population growth, 1750–1850

Notes: These figures presents OLS estimates of equation 1 where the left-hand-side variable is the  $h_t$  population of counties, cities, and parishes respectively. Year fixed effects as well as county, city, or parish fixed effects are included. A vertical line denotes the year 1800, when historians have argued that widespread adoption of the potato began (see section I.1), and dashed lines correspond to a 95% confidence interval based on standard errors clustered at the county, city, or parish level. All regressions are weighted by initial (1750) population and all estimates are measured relative to the (omitted) base year 1750.

Sources: See section II.1 for further details on the underlying data.

Table 3. *Potatoes and population growth, 1750–1850*

|                                     | A. Counties         |                  | B. Cities           |                     |                  | C. Rural parishes   |                     |                    |
|-------------------------------------|---------------------|------------------|---------------------|---------------------|------------------|---------------------|---------------------|--------------------|
|                                     | (1)                 | (2)              | (3)                 | (4)                 | (5)              | (6)                 | (7)                 | (8)                |
| $Potato_t \times Post_t$            | 0.235***<br>(0.071) | 0.313<br>(0.237) | 0.329***<br>(0.086) | 0.370***<br>(0.078) | 0.188<br>(0.129) | 0.111***<br>(0.015) | 0.088***<br>(0.018) | 0.049**<br>(0.024) |
| Region and year fixed effects?      | Yes                 | Yes              | Yes                 | Yes                 | Yes              | Yes                 | Yes                 | Yes                |
| Additional controls?                | No                  | Yes              | No                  | Yes                 | Yes              | No                  | Yes                 | Yes                |
| County $\times$ year fixed effects? | No                  | No               | No                  | No                  | Yes              | No                  | No                  | Yes                |
| Observations                        | 432                 | 432              | 656                 | 656                 | 656              | 15,078              | 15,078              | 15,078             |

Notes: This table presents OLS estimates of equation 2 where the left-hand-side variable is the  $\ln$  population of counties, cities, and parishes respectively. Region fixed effects correspond to county, city, or parish fixed effects respectively. Additional controls include a landlocked indicator, average elevation, distance to the coast, terrain ruggedness, and suitability for growing barley, rye, and wheat, all interacted with a post-1800 indicator. All regressions are weighted by initial (1750) population. Statistical significance based on standard errors clustered at the county, city, or parish level (reported in parentheses) is denoted by: \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.10$ .

Sources: See section II.1 for further details on the underlying data.

where  $P$  is the population of county, city, or parish  $i$  in year  $t$ ,  $Potato$  is the share of land that is at least suitable for potato cultivation,  $Post$  is an indicator variable taking the value 1 for years after 1800 and 0 for all other years,  $\alpha_i$  and  $\lambda_t$  are county, city, or parish and time fixed effects respectively, and  $\mathbf{X}$  is a vector of controls.

Table 3 presents the difference-in-differences estimates from equation 2, showing substantial relative increases in population after 1800 in areas with a higher share of land suitable for cultivating potatoes. The first column presents county-level estimates and, to account for a potential correlation between suitability for cultivating potatoes and other geographical characteristics, column 2 adds controls for altitude, distance to the coast, a landlocked indicator, ruggedness, as well as the average share of land that is highly suitable for cultivating barley, rye, and wheat that are allowed to vary pre- and post-1800.<sup>61</sup> These estimates suggest an average increase in population of 36 per cent (0.31 log points) after 1800 in counties with all of their land suitable for potato cultivation relative to those with no suitable land, though this estimate is imprecise when clustering standard errors at the county level.

Although Swedish cities and towns remained small and grew slowly in the early nineteenth century, the estimates in columns 3 and 4 similarly show that those with more land suitable for potato cultivation grew larger relative to those with less suitable land over the first half of the nineteenth century, with an estimated relative increase of some 45 per cent (0.37 log points).<sup>62</sup> When restricting the identifying variation to within-county differences in suitability in column 5, however, the estimates are reduced in magnitude and are imprecisely estimated, presumably due to the fact that there are relatively few counties with multiple cities. The remaining columns of table 3 report parish-level estimates, which suggest a relative increase in population of about 9–12 per cent after 1800 when excluding

<sup>61</sup> Landlocked counties are those without direct access to the coast, while landlocked cities and parishes are defined as those that are located more than 30 km from the coast.

<sup>62</sup> An alternative outcome would be urbanization rates; for example, Acemoglu et al., ‘Rise’. However, the level of urbanization changed little in Sweden between 1800 and 1850, remaining around 10%, suggesting that this is a less relevant outcome; Schön, *Sweden’s road to modernity*, p. 49.

or including controls. As shown in the final column, the break in parish-level population growth also exists *within* counties (that is, when including county-by-year fixed effects) as suitable parishes saw a statistically significant increase in population of some 5 per cent (0.05 log points) relative to unsuitable areas in the same county after 1800. Although these estimates all suggest that there was an acceleration in population growth in areas with more land suitable for potato cultivation after the crop's introduction around the turn of the century, additional robustness checks are provided next to lend further support to this interpretation.

A first concern is that the estimates simply reflect the fact that a large part of Sweden is unsuitable for potato cultivation. As evident in figure 3, land suitable for potato cultivation is mainly concentrated in the southern and western parts of the country, which raises concerns that the estimates may reflect population shifts to suitable areas that were driven by omitted factors. Indeed, growth shifted toward the south and west between 1750 and 1850, reflecting the relative decline of Stockholm and central Sweden and the greater dynamism of the western and southernmost parts of the country.<sup>63</sup> Table 4, panel A, addresses this concern by examining parish-level population changes in subsamples that exclude the northern parts of the country, and restricts the sample to parishes being located in counties with some of its land being at least moderately suitable for potato cultivation. Across the specifications reported in columns 1 and 2, the positive and statistically significant link between suitability for potato cultivation and population growth persists, which, combined with the evidence from the specifications that include county-by-year fixed effects above, largely reduces concerns that regional shifts of population to these areas confound the impact of the potato.

A complementary way to gauge whether the estimates are likely to reflect omitted factors correlated with soil suitability is to compare relative changes in population between more and less suitable areas. Arguably, if the estimates reflect the availability of more suitable land, one would expect to see faster population growth in areas where the soils are more conducive to potato cultivation relative to locations where the soil is suitable, but less so. Table 4, panel B, reports estimates where the sample is restricted to parishes with moderately suitable and suitable land (column 3) and moderately suitable and highly suitable land (column 4) respectively. These estimates suggest that areas with suitable soils grew more rapidly relative to those with moderately suitable land and that the relative difference in population growth was larger for parishes with highly suitable soils, which is consistent with the higher average potato yields in these areas reported in table 2. Evidence that the increases in population are also apparent in comparisons of areas with *relatively* better soils—that is, exploiting variation along the intensive rather than extensive margin of land suitability—further reduces concerns that the estimates are simply reflecting a differential development across suitable and unsuitable areas.

A final threat to the validity of the estimates is that areas more suitable for agricultural activities in general may have seen an acceleration in growth after 1800, perhaps due to the coming of the enclosures or broader technological

<sup>63</sup> See Söderberg, 'Regional economic development'.

Table 4. Robustness checks

|  | A. Alternative samples |                                   | B. Margin of suitability             |                                    | C. Placebo crops  |                   |                   |
|--|------------------------|-----------------------------------|--------------------------------------|------------------------------------|-------------------|-------------------|-------------------|
|  | (1) Exclude north      | (2) Some moderately suitable land | (3) Suitable vs. moderately suitable | (4) Highly vs. moderately suitable | (5) Barley        | (6) Rye           | (7) Wheat         |
| Suitable land <sub><i>i</i></sub> × Post <sub><i>t</i></sub> | 0.093***<br>(0.018)    | 0.095***<br>(0.018)               | 0.136***<br>(0.031)                  | 0.191***<br>(0.031)                | -0.013<br>(0.012) | -0.011<br>(0.013) | -0.013<br>(0.012) |
| Parish and year fixed effects?                               | Yes                    | Yes                               | Yes                                  | Yes                                | Yes               | Yes               | Yes               |
| Additional controls?   | Yes                    | Yes                               | Yes                                  | Yes                                | Yes               | Yes               | Yes               |
| County × year fixed effects?                                 | No                     | No                                | No                                   | No                                 | Yes               | Yes               | Yes               |
| Observations   | 14,490                 | 13,692                            | 5,880                                | 5,691                              | 15,078            | 15,078            | 15,078            |

Notes: This table presents parish-level OLS estimates of equation 2 where the left-hand side variable is *ln* population. ‘Suitable land’ corresponds to the share of land in a parish that is at least (highly) suitable for potato cultivation in cols. 1–4 and the share of land that is highly suitable for cultivating barley, rye, and wheat in cols. 5–7. Additional controls include a landlocked indicator, average elevation, distance to the coast, terrain ruggedness, and suitability for growing barley, rye, and wheat (omitted in cols. 5–7), all interacted with a post-1800 indicator. All regressions are weighted by initial (1750) population. Statistical significance based on standard errors clustered at the parish level (reported in parentheses) is denoted by: \*\*\**p*<0.01, \*\**p*<0.05, \**p*<0.10.

Sources: See section II.1 for further details on the underlying data.



Figure 5. Potatoes and GDP per capita, 1750–1850

Notes: This figure presents county-level OLS estimates of equation 1 where the outcome is  $\ln$  GDP per capita controlling for county and year fixed effects. A vertical line denotes the year 1800, when historians have argued that widespread adoption of the potato began (see section I.1), and dashed lines correspond to a 95% confidence interval based on standard errors clustered at the county level. The regression is weighted by initial (1750) population and the estimates are all measured relative to the (omitted) base year 1750.

Sources: See section II.1 for further details on the underlying data.

advancements such as the introduction of iron ploughs.<sup>64</sup> A similar acceleration in population growth in areas suitable for cultivating *other* types of crops would thus be an indication that the estimates may not be reflecting the introduction of the potato. Table 4, panel C, provides evidence from three placebo tests that show that parishes with land highly suitable for growing barley, rye, and wheat did not see a similar acceleration in population growth after 1800: each individual coefficient is statistically insignificant and close to zero in magnitude, which shows that the link between soil suitability and population growth after 1800 is uniquely associated with suitability for cultivating potatoes. In sum, these estimates thus provide additional evidence to support the interpretation of the introduction of the potato as a causal and significant factor in accounting for the accelerated pace of population growth from the early nineteenth century onwards.

An expanding population in response to an increase in agricultural productivity is entirely consistent with standard Malthusian predictions, yet this does not reveal anything about whether the increases in agricultural productivity due to the coming of the potato also affected per capita incomes. Recent estimates of regional GDP by Enflo and Missiaia, which construct county-level decadal data for the period under study, are used to examine whether this was the case.<sup>65</sup> Figure 5 shows a flexible specification similar to that above based on equation 1 but using ( $\ln$ ) GDP per capita rather than population as the outcome. While it shows that counties with more land suitable for potato cultivation saw increases in per capita incomes around the turn of the century, when the potato was introduced, it also shows that over

<sup>64</sup> Gadd, *Agrara*, p. 245, however, shows that the adoption of the iron plough in areas suitable for potato cultivation generally took place after the mid-nineteenth century, thus reducing concerns that its adoption is conflated with the spread of the potato.

<sup>65</sup> Enflo and Missiaia, ‘Regional GDP estimates’.

the longer term these relative increases attenuated. Around the mid-nineteenth century, there are no significant differences in per capita incomes relative to a century before.<sup>66</sup> While the increase in agricultural productivity that followed in the wake of the introduction of the potato thus translated into rapid population growth, it did not lead to increases in per capita incomes over the long term, which is consistent with the evidence of a downward pressure on welfare ratios from the 1820s onwards (see figure 2).

Overall, the estimates thus show that cities, counties, as well as rural parishes with more suitable land for potato cultivation saw an acceleration in population growth after the turn of the century, suggesting that the introduction of the potato significantly contributed to the rapid expansion of the Swedish population. Yet the evidence also suggests that mounting Malthusian pressures led to the evaporation of improvements in living standards and per capita incomes over the longer term. Although this interpretation is entirely consistent with Malthusian logic, it is not based on direct evidence of the underlying dynamics of population growth, which prompts a closer look into the margins of population adjustments.

### II.3. *Malthusian dynamics*

A maintained assumption in Malthusian models is that populations adjust to increases in agricultural productivity through increases in marriage rates, which spur increases in fertility, and reductions in mortality rates.<sup>67</sup> An accelerated pace of population growth in areas suitable for potato cultivation after 1800 indeed suggests that at least one of these channels is empirically relevant.<sup>68</sup> To examine the Malthusian margins of adjustment, parish-level data on demographic outcomes recorded by the Tabular Commission are used to compare relative changes in vital rates before and after the widespread adoption of the potato.<sup>69</sup> As above, the main estimating equation takes a difference-in-differences form with the year 1800 as the cutoff:

$$Y_{pt} = \alpha_p + \lambda_t + \delta(Potato_p \times Post_t) + \mathbf{X}_{pt}\beta + \varepsilon_{pt} \quad (3)$$

where  $Y$  is an outcome (for example, births per 1,000 people) for parish  $p$  in year  $t$ ,  $Potato$  again corresponds to the share of land in each parish that is at least suitable for potato cultivation,  $Post$  is an indicator variable taking the value 1 for years after 1800 and 0 for all other years,  $\alpha_p$  and  $\lambda_t$  are parish and time fixed effects respectively, and  $\mathbf{X}$  is a vector of time-varying controls. As argued by Sundbärg, there were pronounced differences in demographic behaviour in eastern, western,

<sup>66</sup> Additional estimates instead using the specification in equation 2 similarly suggest that while there was an increase in GDP in counties with more suitable land after the introduction of the potato around 1800, there was no significant long-run increase in GDP per capita (not reported).

<sup>67</sup> See Malthus, *Essay*; Clark, *Farewell*; Mokyr and Voth, 'Understanding'; Ashraf and Galor, 'Dynamics'.

<sup>68</sup> An alternative channel is inward migration to areas suitable for potato cultivation. Vital rates seem like a more likely margin of adjustment, however, in light of the low rates of internal mobility in the first half of the nineteenth century. For example, Utterström, *Jordbrukets*, p. 5, reports that 92.8% of the population resided in their county of birth as late as 1860, suggesting that migration is a less relevant channel. Furthermore, estimates below provide evidence that natural population growth accelerated in suitable areas, which further reduces concerns that migration is driving the observed increases in population.

<sup>69</sup> See section II.1 for a description of the data.

and northern Sweden, particularly in terms of marriage rates and marital fertility.<sup>70</sup> To reduce concerns that the estimates are influenced by such underlying regional differences, also included are ‘demographic zone’-by-year fixed effects in  $\mathbf{X}$ , so that the identification comes solely from variation in land suitability and vital rates *within* the three zones that Sundbärg identified.<sup>71</sup>

Table 5, columns 1 and 2, present estimates of equation 3, showing that changes in vital rates indeed were an important margin of population adjustment: natural population growth (that is, births minus deaths) saw a statistically significant acceleration in areas suitable for potato cultivation after 1800, which highlights the importance of Malthusian mechanisms. Panels B and C further report estimates providing strong evidence of preventive checks and weaker evidence of positive checks.

As indicated by the estimate in column 3, there was a relative reduction in mortality after the introduction of the potato in areas more suitable for cultivation compared to unsuitable areas. However, when including the full set of controls and controlling for differential changes across demographic zones, the estimate is reduced in magnitude and is not statistically significant, suggesting a more muted change in relative mortality. Ambiguous evidence on the existence of a positive check may be related to the fact that distillation of spirits from potatoes tended to raise mortality considerably among adult men between 1820 and 1850,<sup>72</sup> while it is also more broadly consistent with recent evidence that mortality became less responsive to harvest fluctuations after 1720, while preventive checks strengthened.<sup>73</sup>

Indeed, birth rates increased in areas suitable for potato cultivation relative to less suitable areas over the first half of the nineteenth century (columns 5 and 6). Evidently, the lion’s share of the acceleration in population growth was due to sharp increases in fertility, as the estimate in column 5 implies that roughly two-thirds of the estimated increase in natural population growth in column 1 can be accounted for by increases in birth rates. Weaker results for changes in marital rates are consistent with evidence suggesting that deliberate fertility control was being practised within marriage,<sup>74</sup> though the positive sign in columns 7 and 8 is entirely in line with Malthusian predictions.

Overall, these results support the idea of Malthusian forces operating in Sweden in the early nineteenth century and are broadly consistent with existing evidence from this period.<sup>75</sup> Malthusian constraints, however, were seemingly not fully binding, as areas with land suitable for potato cultivation experienced relative increases in population that were sustained half a century after the introduction of the potato, though the evidence of a downward trend in welfare ratios and per capita incomes above suggests that these areas may have faced mounting Malthusian pressure.

<sup>70</sup> See Sundbärg, *Bygdestatistik*, pp. 4–9.

<sup>71</sup> Including county-by-year fixed effects instead yields very similar results (not reported).

<sup>72</sup> Gadd, ‘Agricultural revolution’, p. 149.

<sup>73</sup> Edvinsson, ‘Vital rates’.

<sup>74</sup> Bengtsson and Dribe, ‘Deliberate control’.

<sup>75</sup> See, for example, Bengtsson and Dribe, ‘New evidence’; Dribe et al., ‘Agricultural revolution’; Edvinsson, ‘Vital rates’; Klemp and Möller, ‘Post-Malthusian dynamics’; Lagerlöf, ‘Malthus’.

Table 5. *Malthusian dynamics, 1750–1850*

|   | A. Natural population growth |                     | B. Positive checks   |                   | C. Preventive checks |                     |                  |                  |
|---|------------------------------|---------------------|----------------------|-------------------|----------------------|---------------------|------------------|------------------|
|   | (1)                          | (2)                 | (3)                  | (4)               | (5)                  | (6)                 | (7)              | (8)              |
|   | Births – deaths              | Births – deaths     | Mortality            | Mortality         | Births               | Births              | Marriages        | Marriages        |
| Potato <sub>p</sub> × Post <sub>t</sub> | 3.071***<br>(0.289)          | 1.828***<br>(0.387) | -1.011***<br>(0.277) | -0.643<br>(0.414) | 2.051***<br>(0.325)  | 1.177***<br>(0.445) | 0.007<br>(0.123) | 0.222<br>(0.153) |
| Parish and year fixed effects?          | Yes                          | Yes                 | Yes                  | Yes               | Yes                  | Yes                 | Yes              | Yes              |
| Additional controls?                    | No                           | Yes                 | No                   | Yes               | No                   | Yes                 | No               | Yes              |
| Demographic zone × year fixed effects?  | No                           | Yes                 | No                   | Yes               | No                   | Yes                 | No               | Yes              |
| Observations                            | 15,054                       | 15,054              | 15,054               | 15,054            | 15,058               | 15,058              | 14,864           | 14,864           |

Notes: This table presents parish-level OLS estimates of equation 3 where the left-hand-side variable is natural population growth (cols. 1 and 2) or the no. of deaths, births, and marriages per 1,000 inhabitants (cols. 3–8) respectively. Additional controls include a landlocked indicator, average elevation, distance to the coast, terrain ruggedness, and suitability for growing barley, rye, and wheat, all interacted with a post-1800 indicator. All regressions are weighted by initial (1750) population. Statistical significance based on standard errors clustered at the parish level (reported in parentheses) is denoted by: \*\*\*p<0.01, \*\*p<0.05, \*p<0.10.

Sources: See section II.1 for further details on the underlying data.

#### II.4. *How much did the potato contribute to Swedish population growth?*

A central question since Esaias Tegnér's contemporary argument that the population explosion of the early nineteenth century was due to 'peace, the vaccine, and the potato' is: how large was the potato's contribution to Swedish population growth? To approximate its contribution, a simple counterfactual exercise is performed here. For each county, an estimate is made for its population in 1850 had the potato not been adopted, by subtracting the estimated contribution of the potato in table 3, column 2, multiplied by the share of land suitable for potato cultivation from each county's (*ln*) population in 1850. Summing over all counties yields a total population in 1850 of 3.48 million and a counterfactual population of 3.38 million. Sweden's population increased by some 1.1 million between 1800 and 1850, which implies that the potato can account for roughly 10 per cent of population growth. As the county-level figures are imprecisely estimated, it may raise the concern that these counterfactual calculations also have a wide margin of error. However, performing a similar calculation using the most conservative parish-level estimate in table 3, column 8, suggests that the potato can account for about 9 per cent of the parish-level population growth over the first half of the nineteenth century, which is further underlined by a similar contribution to city growth (7 per cent) over the same period. In sum, these estimates thus suggest that the potato can account for about one-tenth of the population growth during the half-century after its introduction.

An interesting implication of this result is that the impact of the potato was probably heterogeneous across European countries. Nunn and Qian, for example, estimate that the potato contributed about one-quarter of the population growth in the Old World between 1700 and 1900, thus suggesting that the impact in Sweden was smaller, which is consistent with recent evidence from other Scandinavian countries.<sup>76</sup> Although it is beyond the scope of this article to identify how the spread of the potato differentially affected European countries, furthering our understanding of the heterogeneous impacts of the Columbian Exchange on countries in the Old World remains an interesting avenue for future work.

### III. Conclusions

Sweden saw a veritable population explosion in the first half of the nineteenth century, with a particular expansion of the rural lower classes, which shaped economic, political, and social developments for the remainder of the century. While contemporaries and a long line of historians have attributed the expanding population and the growing rural proletariat to the introduction of the potato, there has been no systematic evidence that establishes this causal link. Evidence in this article suggests that the widespread adoption of potatoes in the early nineteenth century led to transitory improvements in living standards and that it caused a relative population expansion in areas with land suitable for potato cultivation. While the empirical analysis has made it possible to rule out a variety of other

<sup>76</sup> See Nunn and Qian, 'Potato's contribution'. Schmidt et al., 'New crops', estimate that the introduction of the potato contributed about 6% of the growth of Danish market towns between 1672 and 1901. See also Henriksen, 'Disaster', on the role of the potato in Denmark.

potential explanations for the association between the potato and population growth, an important limitation of the available data and empirical approach is that they do not make it possible to identify the relative importance of other factors that have been emphasized as key elements of the agricultural revolution starting in the late eighteenth century. Yet, while an increased commercialization of agriculture, the spread of enclosures, or the introduction of new tools such as iron ploughs and scythes are arguably important to account fully for the accelerated pace of population growth in the first half of the nineteenth century, the empirical evidence presented in this article suggests a key role for the potato as one of its ultimate causes.

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## Appendix I: Calculating welfare ratios

A construction of welfare ratios requires data on wages and prices. Nominal wages for agricultural day labourers in Malmöhus county are obtained from the work of Jörberg, which are based on the Market Price Scales (*markegångstaxor*) that have been shown to track wage developments accurately.<sup>77</sup> To keep the welfare ratios consistent with those reported in the literature, I convert day wages into annual wages by assuming 250 days of paid work per year.<sup>78</sup>

Annual prices required to construct the baskets are mostly available from the works by Jörberg and Myrdal.<sup>79</sup> In particular, Jörberg provides prices for coarse cloth, pine wood, rape oil, rye, butter, peas, tallow candles, and beef.<sup>80</sup> Since prices for coarse cloth are not available for Malmöhus county, I use the average prices for the five counties for which data are available. Beef prices are similarly not available, so instead I use prices from the nearest county that reports such prices (Halland). For fuel, I use the prices of pine wood, which are converted into cords using a conversion factor between cubic metres and cord of 0.28. Assuming that the energy content of pine wood is the average of that reported

<sup>77</sup> See Jörberg, *Prices*, vol. 1, pp. 16–77.

<sup>78</sup> Allen, 'Great divergence'.

<sup>79</sup> Jörberg, *Prices*; Myrdal, *Cost*.

<sup>80</sup> Pea prices are unavailable before 1818, so prices are extrapolated based on the relative price of peas/rye in 1818/23 for the earlier years.

in contemporary firewood manuals (16–17 MBTUs per cord), I use these conversions to calculate the cost of obtaining 2 MBTUs. Soap prices are not available and I therefore use the price of tallow candles to approximate its price. Although most prices required to construct the rye-based basket are thus available from Jörberg, he does not provide prices for potatoes.

Crucially, Myrdal reports annual potato prices from 1830 onwards for Malmöhus county. Unpublished Scanian potato prices for the period prior to 1830 were kindly shared by Mats Olsson and were spliced with the Myrdal price series using the overlap in 1830/5.<sup>81</sup> (The raw correlation between the two series is 0.79 between 1830 and 1900.) Using the Myrdal series and extrapolating prices backward using the relative price of grain and potatoes in 1830/40 instead does not substantively change the results reported in the article. To calculate the calorie content of potatoes and rye respectively, I assume that the calorie content of rye is 3.200 million kcal per ton, based on Gadd.<sup>82</sup> While Gadd notes that 3.200 is a commonly used historical benchmark for the calorie content of rye, he also uses a somewhat higher calorie content (3.433) as an alternative in his calculations. Using this slightly higher level does not affect the interpretation of the welfare ratios presented in the article in a significant way, and the lower value seems more consistent with earlier estimates by Hannerberg, as discussed by Gadd, as well as the one used by, for example, Rönnbäck that reports a calorie content of rye of 3.160 million kcal per ton.<sup>83</sup> For potatoes, Gadd reports a calorie content of 0.971 million kcal per ton that I use to convert potatoes into ‘rye equivalents’ to construct the alternative subsistence basket. Although the calorie content of crops may change over longer periods, due to changes in the use of fertilizers and crop improvements, such changes are unlikely to be of a magnitude that affects the interpretation of the results.

<sup>81</sup> Myrdal, *Cost*.

<sup>82</sup> Gadd, ‘Swedish agricultural production’.

<sup>83</sup> *Ibid.*; Rönnbäck, ‘Consumer revolution’, p. 196.