Online Appendix

A. Calibration

A.1. CES function

The production function parameters (ρ and θ) are calibrated at the sector level and some of the choice and outcome variables (namely, *L*, *A*, and GVA) are calibrated at city-sector level. The data on labour and GVA was retrieved from EUROSTAT's regional statistics for metropolitan regions.[1] Metropolitan regions are NUTS3 regions or a combination of NUTS3 regions which represent all agglomerations of at least 250 000 inhabitants. All variables were calibrated for the year 2005 as the reference year. We choose to use 2005 data instead of introducing another set of strong assumptions that are inevitable to perform economic forecasts for periods in the far future, such as 2081-2100.

The values for the elasticity of substitution (ρ) and the proportion of each input (θ) are estimated at the sector level for the United States, for 1997 and 1960-2005, respectively. The estimation of ρ is taken from Young (2013), and that of θ from Valentinyi and Herrendorf (2008). The sectors differ and were approximated to match the NACE. The sectors used, as well as the years estimated are set out in Table A1.

Finally, estimates of capital stocks at the city level are not available from EUROSTAT. Accordingly, the Perpetual Inventory Method (PIM) was used to estimate *K* from regional-level time series of grossed fixed capital formation (GFCF) also available from EUROSTAT. The PIM is a commonly used approach of measuring capital stocks,[2] based on the idea that they constitute cumulated flows of investment (OECD 2009). It is based on the assumption that I/(g+δ) is the expression for the capital stock in the steady state of the Solow model (Solow 1956).

We start by computing the initial capital stock as

$$K_0 = \frac{I_0}{g + \delta}$$

Where I_0 is our measure of investment (gross fixed capital formation) in the first year available, g is the average geometric growth rate for the investment series between the first year with available data and the last, and δ is the depreciation rate.

Gross fixed capital formation is defined as the resident producers' acquisitions, less disposals, of fixed assets during a given period plus certain additions to the value of non-produced assets realised by the productive activity of producer or institutional units. It is available from EUROSTAT for the NUTS 2

[1] The sectoral distribution was not available for Bilbao for 2005. We took the closest year for which sectoral GVA was available (2008) to calculate each sector's weight, and used the total 2005 GVA to estimate sectoral GVA in 2005.
[2] Two examples are Hall and Jones (1999) and Caselli (2005).

region of London, for the NUTS 2 region of Antwerp, and for the Basque Country, where Bilbao is situated, for each of the sectors used in the analysis.[3]

We use the depreciation rate estimated by the UK Office for National Statistics (ONS) for all three cities. The ONS assumes that plant and machinery has a life of 25-30 years in most industries, which is equivalent to a geometric rate of 5%-9% if growth does not exceed 5% per annum, much lower than the US rate. We choose a rate of 7%. Finally, we use the fixed capital investment deflators from Bluenomics (www.bluenomics.com), which are defined for each country.

We then update the values of K for each year t to give us 2005 levels of capital according to:

$$K_t = I_t + (1 - \delta)K_{t-1}$$

All the sources of data for the calibration of the production function, along with the sectors used to approximate NACE for each, are described in Table A.1.

Table A.1 Sources and Sectors for Calibration

	GVA (Y) and Employment (L)	Gross Fixed Capital Formation	Capital/Labour shares (θ)	Elasticity (ρ)
Source	EUROSTAT; Antwerp, Bilbao, London	EUROSTAT; Antwerp, Basque Country, London	Valentinyi and Herrendorf (2008) United States	Young (2013) United States
Years	2005	Varying	1997	1960-2005
Sectors	Agriculture, forestry and fishing	Agriculture, forestry and fishing	Agriculture	Agriculture
	Industry (except construction and manufacturing)	Industry (except construction and manufacturing)	= Manufactured consumption & Equipment & Construction	= Manufacturing & Metal mining, Coal mining, Oil and gas extraction, Non-metallic mining
	Manufacturing	Manufacturing	Manufactured consumption	= Food and Kindred Products, Tobacco, Textile mill products, Apparel, Lumber and wood, Furniture and fixtures, Paper and allied, Printing, publishing and allied, Chemicals, Petroleum and coal products, Rubber and miscellaneous products, Leather, Stone, clay, glass, Primary metal, Fabricated metal, Non-electrical industry, Electrical industry, Motor vehicles, Transportation Equipment and ordinance, Instruments, Miscellaneous Manufacturing
	Construction	Construction	Construction	Construction
	Wholesale and retail trade, transport,	Wholesale and retail trade, transport,	= Manufactured consumption &	= Transport & Services & Trade

[3] The fact that the gross fixed capital formation data is available only at the regional level (NUTS2, instead of NUTS3) is likely to overestimate each city's capital stock. This in turn may bias the estimations of productivity losses downwards, resulting in conservative estimations of costs to the city economy.

	accommodation and food service activities	accom. and food service activities	Services	
	Information and communication	Information and communication	Services	Construction
	Financial and insurance activities; real estate activities; professional, scientific and technical activities; administrative and support service activities	Financial and insurance activities; real estate activities; professional, scientific and technical activities; administrative and support service activities	Services	Finance, Insurance & Real Estate
	Public administration and defence; compulsory social security; education; human health and social work activities; arts, entertainment and recreation; other service activities; activities of household and extra-territorial organizations and bodies	Public admin. and defence; compulsory social security; education; human health and social work activities; arts, entertainment and rec.; other service activities; activities of household and extra-territorial organizations and bodies	Services	Government Enterprises

Notes: The = is used to indicate that an average of more than one sector was used.

A.2. Productivity loss function

As an international standard, we use ISO standard 7243:1989 on heat stress at different work intensities to estimate worker productivity loss functions (ISO 1989). Following Kjellstrom et al. (2009), we estimate the WBGT at which the ISO recommends an average, acclimatised worker should perform work at 100%, 75%, 50% and 25% productivity, as well as the threshold WBGT above which workers are performing at or very close to zero capacity. Using the method set out by Kjellstrom et al. (2009) we estimate the WBGT for each type of work and for each work/rest ratio. The results are shown in Table A.2.

Table A.2 Worker productivity at different work intensities, using ISO standards for an average acclimatised worker wearing light clothing (ISO 7243)

Worker productivity (per hour)	Light work (*WI* = 180W) WBGT (°C)	Moderate work (*WI* = 295W) WBGT (°C)	Heavy work (*WI* = 415W) WBGT (°C)
100% (full work)	31.0	28.6	26.8
75%	31.5	29.0	27.8
50%	32.0	30.5	29.5
25%	32.5	31.7	31.2

Using the estimations in Table A.2, productivity loss functions for five different work intensities (WI) were calculated. The functions, set out below, are also shown in Figure A.1.

Work intensity 1 (WI_1 = 180W):

$$P_1 = \begin{cases} 1 & WBGT < 31 \\ 16.5 - 0.5WBGT & 31 \leq WBGT \leq 33 \\ 0 & WBGT > 33 \end{cases}$$

Work intensity 2 (WI_2 = 240W):

$$P_2 = \begin{cases} 1 & WBGT < 29.6 \\ 10.1 - 0.3WBGT & 29.6 \leq WBGT \leq 32.9 \\ 0 & WBGT > 32.9 \end{cases}$$

Work intensity 3 (WI_3 = 295W):

$$P_3 = \begin{cases} 1 & WBGT < 28.3 \\ 7.20 - 0.2WBGT & 28.3 \leq WBGT \leq 32.8 \\ 0 & WBGT > 32.8 \end{cases}$$

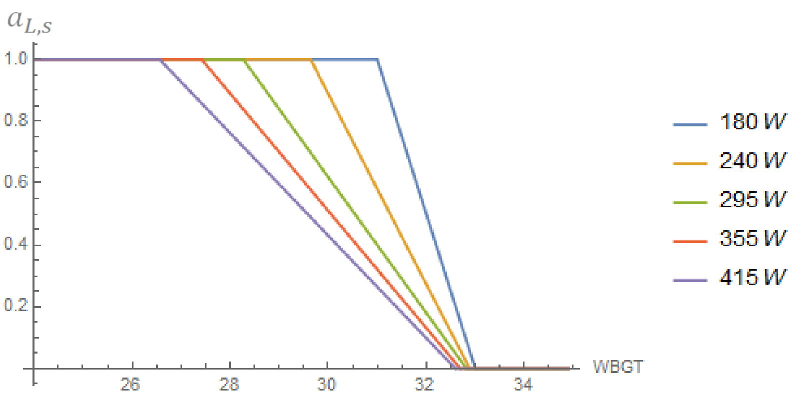
Work intensity 4 (WI_4 = 355W):

$$P_4 = \begin{cases} 1 & WBGT < 27.4 \\ 6.2 - 0.2WBGT & 27.4 \leq WBGT \leq 32.7 \\ 0 & WBGT > 32.7 \end{cases}$$

Work intensity 5 (WI_5 = 415W):

$$P_5 = \begin{cases} 1 & WBGT < 26.6 \\ 5.4 - 0.2WBGT & 26.6 \leq WBGT \leq 32.6 \\ 0 & WBGT > 32.5 \end{cases}$$

Figure A.1 Hourly worker productivity loss functions based on ISO standards, sector s



The productivity loss functions for work intensities WI_1 (180W), WI_3 (295W) and WI_5 (415W) were calculated directly from Table . In addition, we estimated functions for WI_2 (240W) and WI_4 (355W) by taking the mean average of the other loss functions. This provided a set of loss functions, each of which can be allocated to a specific sector of the economy.

We tested the robustness of results based on the ISO standards by comparing them with the US national standard provided by the National Institute for Occupational Safety and Health (NIOSH). The WBGT for each work intensity is shown in Table A.3. In both the ISO and NIOSH cases, workers are assumed to be acclimatised. This provides a relatively conservative estimate of heat stress impacts on individual productivity. However, non-acclimatised loss functions can also be used, for example based on estimates provided by NIOSH (see Table A.4).[4]

Table A.3 Worker productivity at different work intensities, using US standards for acclimatised workers (NIOSH)

Worker productivity (per hour)	Light work (*WI* = 180W) WBGT (°C)	Moderate work (*WI* = 295W) WBGT (°C)	Heavy work (*WI* = 415W) WBGT (°C)
100% (full work)	29.5	27.5	26.0
75%	30.5	28.5	27.5
50%	31.5	29.5	28.5
25%	32.5	31.0	30.0

Table A.4 Worker productivity at different work intensities, using US standards for non-acclimatised workers (NIOSH)

Worker productivity (per hour)	Light work (*WI* = 180W) WBGT (°C)	Moderate work (*WI* = 295W) WBGT (°C)	Heavy work (*WI* = 415W) WBGT (°C)
100% (full work)	27.5	25.0	22.5
75%	29.0	26.5	26.5
50%	30.0	28.0	28.0
25%	31.0	29.0	29.0

To allocate an appropriate productivity loss function to each sector, we used the classification of different job activities by work intensity used by the British and European standards on heat stress, BS EN 27243:1994, and based on the ISO 7243:1989 (see British Standards Institution 1994). Table A.5 summarizes the resulting relationship between work intensity and sector.

[4] The UK's HSE Health and Safety Executive (Health and Safety Executive, 2013) also establishes a legal obligation on employers to provide a 'reasonable' temperature in the workplace, but they do not define a threshold for a maximum temperature. They argue that a meaningful threshold cannot be given for maximum temperature as it is "still possible to work safely provided appropriate controls are present".

Table A.5 Estimated work intensity in different sectors of the economy

Sector	Average Work Intensity (W)	Work Intensity Category (WI)
Agriculture, forestry and fishing	355	Moderate/high (4)
Other Industry	295	Moderate (3)
Manufacturing	240	Light/moderate (2)
Construction	355	Moderate/high (4)
Wholesale and retail trade	240	Light/moderate (2)
Information and communication	180	Light (1)
Financial and insurance activities	180	Light (1)
Public administration and defence	240	Light/moderate (2)

For simplicity, we assume that work in the agricultural and construction sectors are performed outdoors, while work in all other sectors is performed indoors. As a baseline, we assume all individuals work from 9h-13h and 14h-17h, under legal ventilation standards established in Antwerp, without air conditioning.

We also assume that losses to productivity due to heat can potentially occur during the three hottest summer months (not in other months of the year) and that all workers take their holiday during the summer period. As a result, we estimate losses for only 2 out of the 3 months. This is a very conservative estimation as losses are likely to occur in more months throughout the year, especially for the far future. Hence, the end-of-the-century results are actually a lower limit on the true fraction of lost working hours and cooling costs.

A.3 References

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